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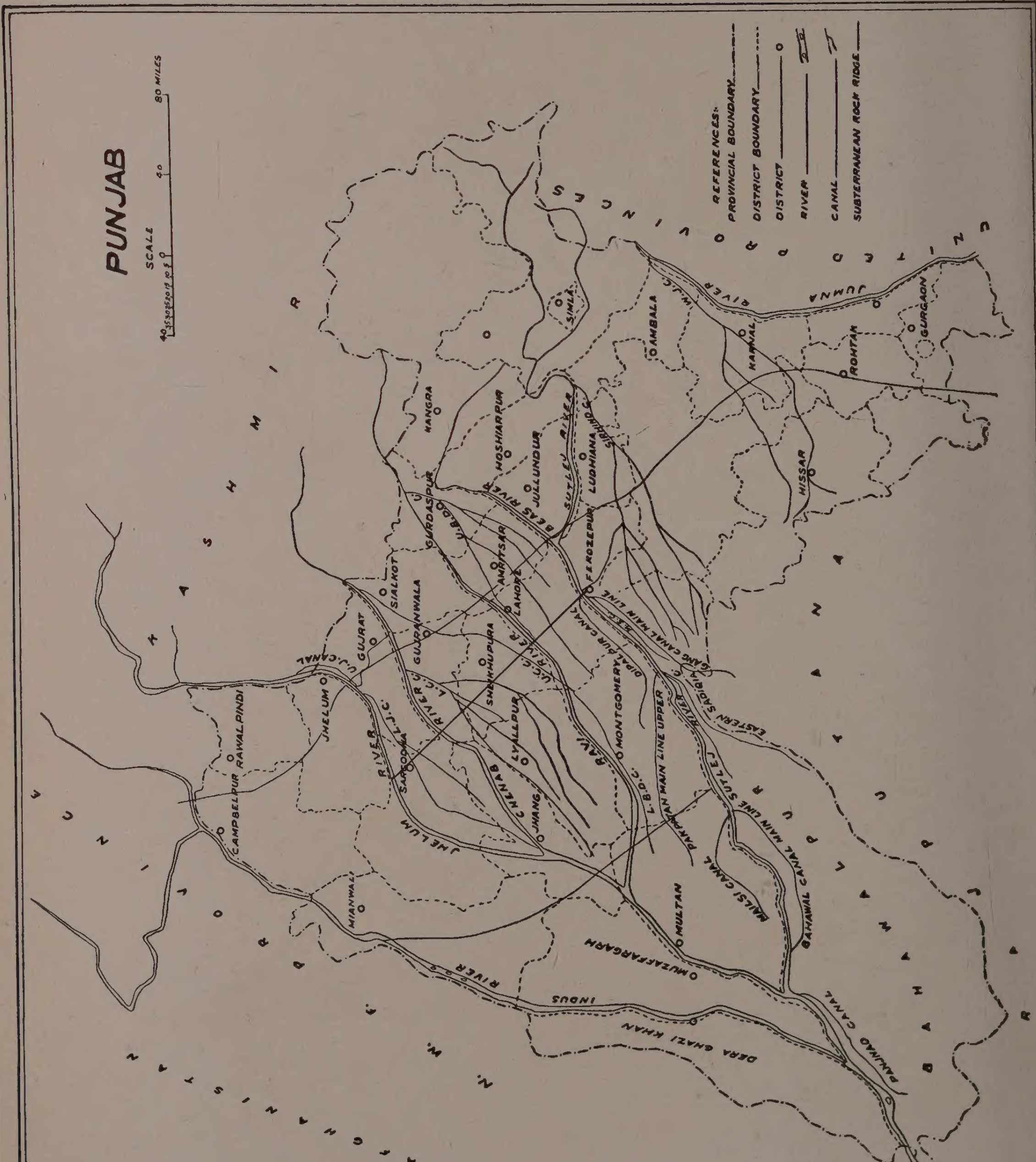
PUNJAB
SCALE
80 MILES
REFERENCES:-
PROVINCIAL BOUNDARY
DISTRICT BOUNDARY
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UNITED PROVINCES
N. W. F. PROVINCE
AFGHANISTAN
BAHAWALPUR
RAJPUTANA
SIMLA
AMBALA
KARNAL
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LAHORE
SIALKOT
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SHEIKHUPURA
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SARGODHA
JHELUM
RAWALPINDI
CAMPBELPUR
MIANWALI
MULTAN
MUZAFFARGARH
DERA GHAZI KHAN
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SIRHIND C.
DIPALPUR CANAL
EASTERN
SADIQIA
HAVELI
PAKPATTAN MAIN LINE UPPER
MAIN LINE SUTLEJ
BAHAWAL CANAL
PANJNAD CANAL
GANG CANAL MAIN LINE

ORIGINAL ARTICLES

SOME IRRIGATION PROBLEMS IN THE PUNJAB

BY

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(With Plate X and nine text-figures)

I. INTRODUCTION

IRRIGATION problems in the Punjab cover a very wide field which includes construction and maintenance of headworks, river training, maintenance of canals, the distribution and use of irrigation water with which are associated the waterlogging and the deterioration of land due to the accumulation of salts at the surface. Since about 40 per cent of the revenue of the province is derived directly from irrigation and a further 45 per cent is obtained indirectly, the financial aspect of irrigation is also of considerable importance and presents problems which require solution.

A brief description of the rivers and their associated irrigation systems will assist in the appreciation of the problems with which the Irrigation Department is faced. The word ' Punjab ' means the land of the Five Rivers, these being the Sutlej, the Beas, the Ravi, the Chenab and the Jhelum. With the exception of the Beas each of the rivers has an associated canal system or systems. The eastern boundary of the Punjab is the Jumna river from which the Western Jumna Canal system takes off. On the west, the Punjab is bounded by the Indus and the construction of a canal system to use the waters of the Indus to irrigate the desert areas between the Indus and the Chenab rivers has now commenced. During the winter the discharges in the rivers are low, the water being derived from seepage in their catchment areas. The sources of the Punjab rivers are situated in the high portions of the Himalayas. The supply of water in the rivers in the spring is, therefore, dependent upon the winter snowfall and the rate at which the snow melts. Generally, the rivers start rising in March and carry silt which is grey in colour and which has resulted from the physical weathering of the rocks in the higher ranges of the Himalayas. The monsoon usually breaks towards the end of June, and with the high rainfall in the low hills river supplies in summer are high and the silt carried by rivers changes from grey to red due to the erosion of the hills usually below 9,000 ft. in height.

A typical canal system in the Punjab consists of a barrage across the sandy bed of the river, the headworks of the canal, the main line, branches, distributaries and minors. The minors discharge into the watercourses, for the maintenance of which the zemindar is responsible. As the barrage is constructed on the sandy bed of the river, one of the main problems has been

to design the work so that it will withstand the uplift pressures due to the water which it heads up. Until recently designs for barrages were based on Bligh's [1927] Creep theory. The work carried out at the Irrigation Research Institute and investigations of pressures on actual structures have shown that Bligh's basis for design is unsound. The subject of uplift pressures has been investigated experimentally and theoretically in the laboratory, and practical studies have been made in the field. The results of these studies have been embodied in a number of publications of the Irrigation Research Institute and have been collected in a publication of the Central Board of Irrigation [Khosla, Bose and McKenzie Taylor, 1936]. It is now possible to design a barrage which will be safe against uplift pressure and for which the maintenance costs will be low.

The practice in the Punjab is to construct a barrage in a dry portion of the river-bed. On completion of construction the river is diverted on to the barrage by closing the main channel with an earthen embankment. In recent years models of the river and barrage have been made in order to study the difficulties that will be encountered during the construction and diversion periods. These models have given valuable information and have resulted in considerable savings in the costs of construction.

The canal systems of the Punjab consist of two types which may be called 'irrigating' and 'carrier'. In an irrigating canal system the whole of the water taken in at the head of the canal is used for the irrigation of crops in the culturable commanded area. The main purpose of a carrier canal is to transfer water from one river system to another in order that the supplies may be balanced and deficiencies in one river may be made good from the surplus in another. By means of these carrier canals, water is transferred from the Jhelum to the Chenab, from the Chenab to the Ravi, and now from the Ravi to the Sutlej. The construction of these carrier canals has enabled the most efficient use to be made of the whole of the water available in the Punjab rivers during the winter months.

The soils of the Punjab plains consist of alluvium which in some cases is covered by aeolian deposits. The soil generally contains from 10 to 15 per cent of clay and has an average depth of 10 ft. The soil crust overlies a sand in which the water-table is situated. The soil itself has generally an alkaline reaction due to the presence of sodium in the clay complex. Sodium salts are usually present in the soil crust and the control of their movement is one of the major problems of irrigation and agriculture. The soils usually have a high content of calcium carbonate which is sometimes present in the nodular form, locally called *kankar*. Wilsdon and Bose [1934] carried out a geodetic survey of certain portions of the plains and have shown that a subterranean rock ridge is present. This ridge is composed of rhyolite and it divides the Punjab into two areas, so far as its underground characteristics are concerned. The importance of this rock ridge in connection with the rise of water-table and waterlogging will be dealt with later.

The climate of the Punjab may be described as semi-arid. The major portion of the rainfall occurs in the period June to September, while winter rains, not exceeding one or two inches, occur in December and January. Precipitation decreases as the distance from the Himalayas increases. The rainfall in the foot-hills averages about 30 in. but a large part of the Punjab has rainfall

of under 20 in. a year and in the driest portion the rainfall amounts to only 4 in. The irrigated area is situated in the rainfall belt below 20 in. The maximum temperature usually occurs in May and June and may be as high as 120°F. The minimum temperature occurs in January when two or three degrees of frost may be recorded. The seasons in the Punjab are known as *kharif* and *rabi*, the *kharif* season extending from April 15 to October 15 and the *rabi* from October 15 to April 15. In the *kharif* season the main crops are cotton, sugarcane, rice and maize. In the *rabi* season wheat is the principal crop though *toria* (*Brassica campestris*), gram, and barley are also grown. The *toria* crop presents a difficulty regarding the use of the available water towards the end of the *kharif* season since it is sown on *kharif* water and is matured on the *rabi* supplies.

II. Construction and maintenance of canal systems

The main factors to be considered in the design of a canal system are the discharge in the river in winter and the slope available which determines the grade of silt which the channel can carry. The principal factor upon which the maintenance of a canal depends is the silt which enters the headworks and is distributed throughout the canal system. In the past attempts have been made to draw rules for design taking into account the type of silt expected to form the bed of the channel. The most notable of the earlier works on this subject is that of Kennedy [1896]. The Punjab canals have largely been designed according to the rules which he evolved. Lacey [1930] published a paper on stable channels in alluvium and introduced the silt factor. As a result of Lacey's paper the importance of silt in the design of a canal system was again brought to the fore. Lacey's equations have now been adopted for design in many provinces in India. During the past five years investigations have been in progress in the Punjab with the object of introducing a characteristic of silt into the equations for design. The bed silt of the Punjab canals usually lies between 0·075 mm. and 0·6 mm. in diameter. The silt-transporting power of water in a canal system is determined by the slope of the canal and its discharge. Material which is too coarse to be transported will be deposited on the beds of the channels. This deposition of silt on the bed may reduce the capacity of the channel which can only be restored by raising the banks. It may also induce the banks to scour with resultant breaches unless they are strengthened. Silt therefore is one of the main causes of the high cost of maintenance of some canal systems.

A series of 24 sites known to be in regime was selected on two canal systems. These sites have been under daily observation for the past five years. The usual hydraulic data have been collected and in addition a sample of the bed silt present in the canal at the sampling site was taken. The mean diameter of the particles composing the bed silt was determined by means of Vaidhianathan's [1933] siltometer. The results were examined by the methods of correlational analysis and a relationship between S, the slope, Q the discharge and m the mean diameter of the silt particles was established [Bose and Malhotra, 1939]. This relationship is as follows :—

$$S \times 10^3 = 2{\cdot}09 \quad \frac{m^{\cdot 86}}{Q^{\cdot 21}}$$

Since this formula has been derived by the study of regime sites of canal systems in the Punjab, its application was at first limited to these systems. Recently, however, it has been shown that it also applies to regime reaches of the Mississippi river and may be found of more general use than was originally indicated.

The formula has a number of important applications. If the mean diameter of the silt in suspension in the river at the site of a proposed headworks is known, it is now possible to determine whether with the designed discharge and the slope available a canal can be constructed which will be non-silting and non-scouring. If this silt is too coarse for the proposed canal then measures can be taken at the head to exclude or extract the harmful silt from the water entering a canal. For this purpose silt excluders and extractors have been added to the headworks of the Main Line Canal of the recently completed Haveli Project.

The formula can also be used for the control of silt in an old canal system. Considerable trouble is being experienced on the Upper Bari Doab Canal, Punjab, due to the coarse silt entering the head. Silt excluders have now been designed and are to be constructed. In this case the de-silted water will tend to pick up silt already present on the bed of the channel with the result that unless measures are taken to prevent it the silt trouble will be transferred to the lower portions of the system. The canal can be divided into sections and, knowing the grade of silt on the bed and the discharge passing through these sections, the slope required to prevent the movement of silt can be calculated. By the construction of falls, the slope can be reduced below that necessary for silt movement and, hence, the canal can be stabilized with reference to the bed silt now present. It is intended to stabilize the Upper Bari Doab Canal by this method.

In order to design silt excluders and extractors it is necessary to know the distribution of silt in the depth of water to be treated. This having been determined, models are constructed to simulate the conditions at the excluding or extracting site. The models are studied with the object of fixing the depth to which extraction can take place, the discharge to be run to secure maximum efficiency, and the pressure conditions in the extractor which govern design. An account of the model experiments in connection with the design and operation of the silt excluder on the Upper Bari Doab Canal has already been published [McKenzie Taylor, 1937].

III. Rise of the water-table and waterlogging

The introduction of irrigation is almost invariably followed by a rise of the water-table which may under certain conditions lead to waterlogging. To the rise in the water-table has also been attributed in the past the deterioration of land due to the accumulation of sodium salts in the surface layers of the soil.

In the Punjab attention was first drawn to the subject of waterlogging by the conditions on the Western Jumna Canal. Malaria became a serious menace in the cantonments situated in the irrigated areas of this canal about the year 1857. The Government of India ordered the realignment of the canal and the construction of a drainage system in order to ameliorate the conditions.

In 1870 the rise of the water-table led to waterlogging in certain areas irrigated by the Sirhind Canal. Notes made by the Executive Engineers of this time show that they attributed this rise in the water-table to rainfall, but a systematic investigation of the cause of the rise was not possible owing to the absence of data. Observations of the water-levels in wells was started in 1870 in the Sirhind Canal area, and it has been the practice since that date, for each new canal constructed, to lay out a series of lines of wells in order to obtain a record of the variations in the water-table levels. These observations of the water-levels in the wells are made twice a year, in June and in October. In June, following a long dry period, the water-table is at its greatest depth from the surface. The variations in the June-to-June readings of the water-level give a measure of the permanent additions to the water-table. The readings of the well levels in October are made when the water-table is at its minimum depth from the surface following the monsoon period. Additions to the water-table made by the monsoon are obtained by comparing the June and October records of the well levels. A large number of rain-gauge stations have been established in the areas commanded by the canals, discharge measurements at control points in canal systems are available and river gauges are recorded daily. With the data now available from these records it has been possible to examine the rise of the water-table with reference to the factors which may be operating.

Before discussing the investigations which have been undertaken, it is necessary to draw attention to the geodetic survey which was made by Wilsdon and Bose which has been previously mentioned. The geodetic survey showed the presence of an underground rock ridge running across the Punjab at right angles to the direction of the flow of the rivers. This underground ridge divides the Punjab into two parts in which the water-table is behaving differently. Upstream of the rock ridge the water-table has approached the soil surface and in certain portions of the area waterlogging occurs. Downstream of the rock ridge the water-table is at a considerable distance from the soil surface and its rate of rise is constant at one foot per year over a considerable area. The first investigations that were undertaken on the rise in the water-table were made in the area upstream of the rock ridge; recently they have been extended to the area downstream of the rock ridge.

The first systematic study of the available data was made by Wilsdon and Sarathy [1927-28] for the area of the Rechna and Chaj Doabs upstream of the rock ridge. They weighted the data of the rain-gauge stations and observation wells so that the records might be truly representative of the whole area. They combined the weighted rainfall with the recorded irrigation in such a way that the total water applied (W) was represented as six independent variables of a fitted ploynomial of the fifth order. In order to eliminate secular changes from the weighted records of well fluctuations the best exponential curve was fitted. The change in average well levels, corrected for slow change, was correlated with the constants of the polynomial fitted to the (W) distribution. Regression curves were thus obtained which indicated a considerable variation throughout the year in the proportion of water which reaches the water-table from each application. An example of the regression curves obtained is given in Fig. 1. The conclusion reached was that both the rainfall and irrigation contributed to the rise in water-table, but that the

major cause of the rise was the monsoon rainfall. As a result of their work they recommended canal closures in order to reduce the seepage component of the irrigation load. This measure was tried, but it resulted in dislocation of the agricultural system, and has now been abandoned as an anti-water-logging measure.

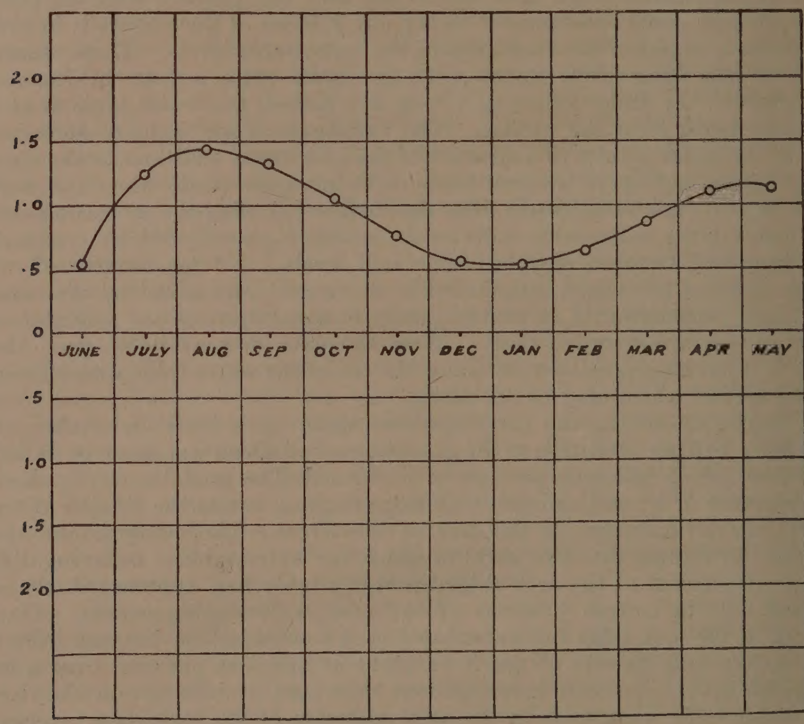

FIG. 1. Monthly regression curve of rainfall for the Upper Chenab Canal (1907-08 to 1930-31)

The well observations, rainfall and canal discharge data for the Upper Chenab Canal area were examined by McKenzie Taylor, Malhotra and Mehta [1933]. This area was also situated upstream of the underground rock ridge. The conclusions they reached confirmed those of Wilsdon and Sarathy regarding the importance of the monsoon rainfall as a factor in the rise of the water-table. The relation between the rise of the water-table and the monsoon rainfall in the Upper Chenab Canal area is shown in Fig. 2 and is expressed by the equation.

$$\delta d = 1 \cdot 54 R - 3 \cdot 77$$

where δd is the rise in the water-table, and R is the rainfall in inches. They discussed the importance of this equation with reference to drainage and the stabilization of the water-table.

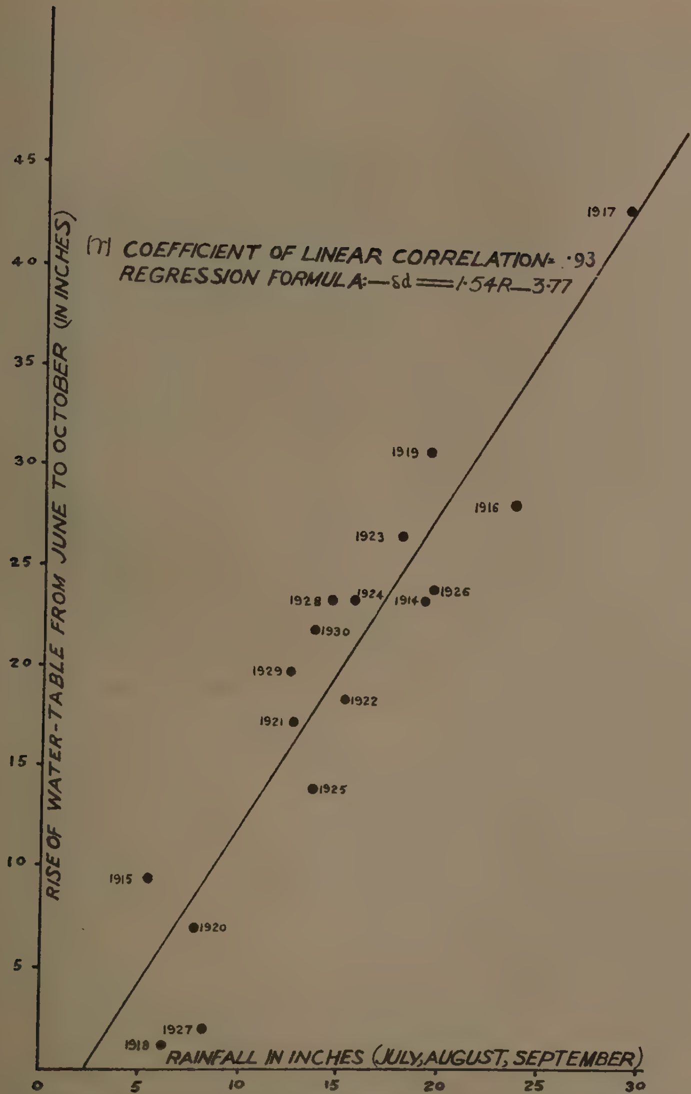

FIG. 2. Rainfall (July-Sept.), rise of the water-table (June-Oct.) 1914-30, Upper Chenab Canal area

As a result of the study of the Upper Chenab Canal area it was suggested that a drainage system to deal with the storm water of the monsoon period should be constructed. A comprehensive drainage system has been under development for the past five years and it seems probable from the results already achieved that the water-table in this area may be stabilized.

An investigation of the rise of the water-table in the Rechna Doab downstream of the underground rock ridge has recently been carried out by Malhotra [1938]. The methods he used were similar to those of the previous workers and he concluded that either the same factors were operating upstream and downstream of the rock ridge or that the water-table upstream of the rock ridge was directly influencing that downstream.

It has been suggested that the presence of the underground ridge has resulted in the heading up of the sub-soil stream and that the rise of the water-table downstream of the ridge is now taking place due to the underground water flowing over the crest. Some support is lent to this theory by the comparison of the conditions in the Punjab with those of the United Provinces. The geodetic survey has shown that the underground ridge is continuous through the Punjab and the United Provinces. In the Punjab, the underground ridge crosses the direction of the flow of the river systems and waterlogging occurs upstream of the ridge. In the United Provinces the underground ridge runs parallel to the direction of the flow of the river systems and, although irrigation has been developed considerably, no waterlogging is reported from the United Provinces.

The irrigation load may be divided into two parts with reference to additions to the water-table . A certain amount of water is lost by seepage from canals and added to the water-table. Of the water used for the irrigation of crops a certain amount passes to the sub-soil and may raise the water-table. Since seepage and irrigation are almost constant from year to year, it is impossible to analyse their effects by statistical methods.

During recent years considerable attention has been devoted to seepage losses and a number of methods have been used for their determination. Malhotra [1936] investigated the losses for the Jhang Branch, Lower Chenab Canal, and for a reach of the Kasur Branch of the Upper Bari Doab Canal. In these cases discharges were taken at the head and tail of the reaches under investigation by means of carefully calibrated current meters. In order to eliminate instrumental, experimental and personal errors the observers and instruments were so changed between the head and the tail of the reaches that the errors could be determined by statistical methods. In the case of the Jhang Branch, Malhotra found the losses to be 13 cusecs per million square feet of wetted perimeter and for the Kasur Branch 7·5 cusecs per million square feet of wetted perimeter.

Vaidhianathan [1938] used a physical method for determining the seepage on a cross-section of the Lower Bari Doab Canal. He sank a series of pipes into the water-table on a line at right angles to the canal. The resting levels of the waters in these pipes were taken after a long canal closure. On re-opening the canal he observed the rises in water-levels in these pipes until a steady gradient from the canal had been established. Knowing the moisture content and the transmission constant of the sand above the water-table he calculated the seepage flow and found it to be, in this case, five cusecs per million square feet of wetted perimeter.

Crump installed three sharp-crested weirs of the Rehbock type on the Kasur Branch of the Upper Bari Doab Canal in the same reach as that investigated by Malhotra. These sharp-crested weirs are very sensitive to aeration and great care is necessary to ensure that they are identical. Having

taken the necessary precautions, Crump has shown that Malhotra's figure of 7·5 cusecs per million square feet of wetted perimeter is probably correct.

A further investigation of seepage has been undertaken by Blench [1939] who has considered the discharge records of the canal for a period of 20 year; Difficulties in dealing with these records have arisen owing to the methods of measurements varying from site to site. If the methods of measurements of discharge are not similar, then errors are introduced and the results are not comparable. Blench has attempted to correct the discharge records by re-calibrating the flumes according to one method. His results show that on the average seepage losses from the Punjab canals may be taken to be eight cusecs per million square feet of wetted perimeter with an observed maximum of 25 cusecs per million square feet of wetted perimeter, depending upon the type of soil forming the bed of the canal.

Assuming that the average figure of eight cusecs per million square feet of wetted perimeter is correct, it will be seen that canals may make considerable additions to the water-table by means of their seepage losses. Attempts have been made to evaluate the additions to the water-table by considering the June-to-June figures. The results obtained in the Lower Chenab Canal agree closely with the calculated losses from the main line and branches of the Lower Chenab Canal itself. The conclusion has been drawn that, if seepage could be prevented, the water-table would be stabilized. Superficially this may seem a reasonable conclusion. A detailed examination of the rise, however, shows that it is so uniform in magnitude over the whole area of the doab that it seems unlikely that the additions to the water-table on a series of isolated lines can be an important factor in the general rise. Figs. 3 and 4 show the uniformity of the rise at five-year intervals on a cross-section and

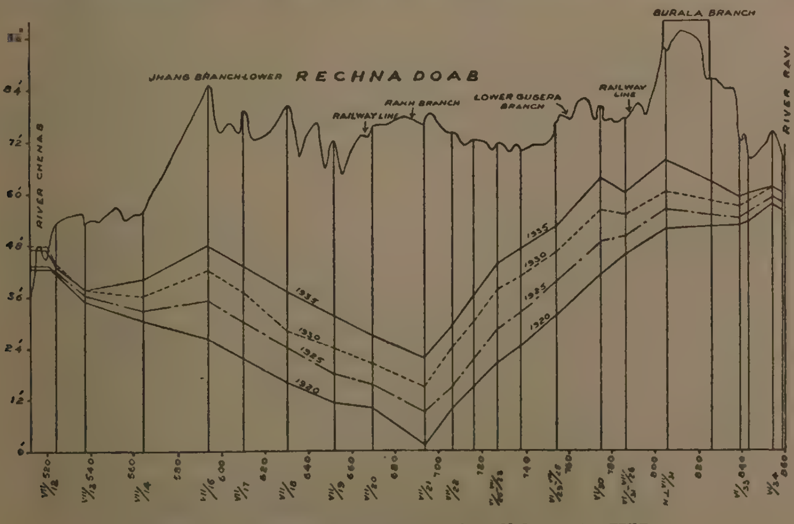

FIG. 3. A section of provincial well line No. XII

Scale { Horizontal 1 in. = 16 miles
Vertical 1 in. = 40 ft.

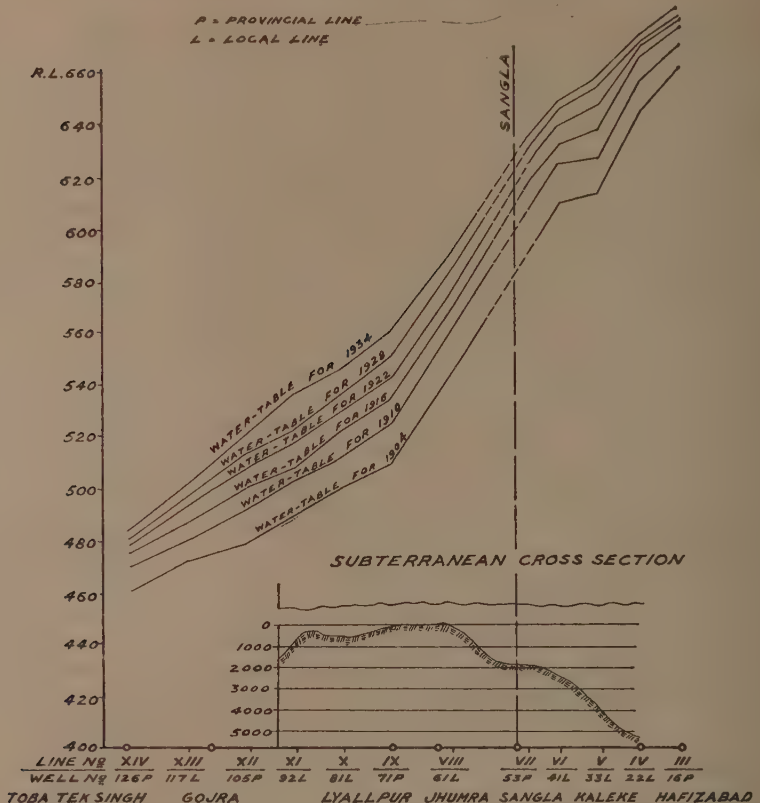

FIG. 4. Longitudinal section showing sub-soil water levels at various periods in the Rechna Doab

(Scale 1 in. = 32 miles)

a longitudinal section of the doab. These sections are typical of the whole area. Lining of canals is probably to be undertaken, but it is doubtful whether it will prove an effective anti-waterlogging measure.

Mehta [1938] has recently carried out experiments to determine the additions made to the water-table by the irrigation of cotton and rice. Pipes were inserted in plots under these crops and in the surrounding areas. Water-table levels were recorded before irrigation commenced and after each irrigation during the growing period of the crops. The results which he has obtained so far show that with the normal irrigation of cotton the water-table under an irrigated area rises 9 in. during the growing period of the crop. In the case of rice the rise of the water-table was almost 4 ft. He calculates that 11·3 per cent of the total water used for rice and 3·5 per cent of the water used for cotton are added to the water-table. As irrigation is evenly distributed over the culturable commanded area of a canal it appears that the irrigation water added to the water-table is an important

factor of a uniform nature. Further work on this subject is in progress so that data may be available for reaching reliable conclusions.

The importance of determining the part played by the various factors in the rise of the water-table lies in the decisions that must be taken to prevent waterlogging. In the year 1926 the position was regarded as so serious that a Waterlogging Enquiry Committee was established. As a result of the investigations of this committee Lindley [1928] forecast areas which would become waterlogged within a period of 10 years if the same rate of rise continued. In 1937 an investigation was undertaken to determine how far Lindley's forecast had been fulfilled. It was found that the areas that could be classified as waterlogged were considerably less than had been forecast. An examination of the well records was made, and it was found that as the water-table approached the surface the rate of rise declined and finally the rise ceased. An examination of the soil crust in the areas surrounding these wells has shown that the water-table does not enter the soil crust and that the rise ceased when the water-table touched the lower side of the crust. This conclusion is probably peculiar to the Punjab since the soils are alkaline and frequently the soil crust becomes impermeable. If the bottom of the soil crust becomes impermeable, then the rise of the water-table may not be so serious as was once thought from the waterlogging point of view. From the examination of a large number of wells it has been shown that if the soil crust is 10 ft. or more in thickness then the normal indications of waterlogging are not apparent at the soil surface. At the present stage of the investigation it is possible to say that areas in which the soil crust has a minimum thickness of 10 ft. are in no danger of waterlogging. It is now proposed to carry out a soil survey to enable a forecast to be prepared of danger areas on this basis.

IV. Deterioration of land due to the accumulation of sodium salts

It is generally recognized that the introduction of irrigation in a semi-arid region is followed by the accumulation of salts in the surface layers of the soil. It is unfortunate that until recently soil surveys were not made as a preliminary to project preparation, so that soil conditions in the pre-irrigation period can only be surmised.

The formation of salt soils under irrigation has been attributed, in some cases, to the salts present in the irrigation water. Analyses of the canal waters show that this cause is not effective in the Punjab. Until recently the explanation of the deterioration of land, which found most general acceptance was that the salts were derived from the water-table as a result of its rise and the evaporation of water at the soil surface. It is probable that this view was accepted because the investigations had been confined to areas with a high water-table. Doubts have now been thrown on this explanation as the result of the extension of the investigations to areas in which the water-table is at a considerable distance below the soil surface and contact between the water-table and the soil surface is precluded.

The salt responsible for the deterioration of the Punjab soils is sodium sulphate. Sodium chloride and sodium carbonate may be present, but usually in small quantities. An examination of the soil profiles of unirrigated areas has shown that sodium sulphate is distributed throughout the soil crust,

It appears, therefore, that it must have been deposited along with the alluvium now forming the soil. The origin of the salt present in the Sambhar lake, Rajputana, which is situated to the south-east of the Punjab has been investigated by Holland and Christie [1909-23]. They attribute the replenishment of the salt in the lake to the salt-laden wind blowing from the Rann of Cutch and the deposition of the salt in the Sambhar lake region. This explanation may be valid for the Sambhar lake, but cannot apply to the Punjab where the salt present is sodium sulphate. A possible explanation of the presence of sodium sulphate in the alluvium of the Punjab is indicated by the fact that sodium sulphate is deposited from a solution of mixed salts at a temperature of —3°C. Glacial conditions are known to have occurred in the Punjab, and it appears probable that the sodium sulphate was deposited along with the alluvium during a glacial period. Support is lent to this suggestion by a consideration of the extension of the alluvium into Sind where the main salts present are sodium chloride and calcium chloride and sodium sulphate has become of minor importance.

For the past 12 years revenue officials have been making annual surveys of selected areas to determine the rate at which land is going out of cultivation. The data show that the recorded rate is of the order of 25,000 acres per annum. This figure may be regarded as a minimum, since land is known to be going out of cultivation in areas not under survey and the accuracy of the revenue records is open to question. A recent check of a revenue survey by means of photographs taken from the air indicates that the rate of soil deterioration is much higher than 25,000 acres per annum.

In order to investigate the theory that the rise of the water-table was the primary cause of the formation of salt efflorescence and to obtain data as to the depth at which the water-table might become active in this connection, a series of villages with the water-table at varying depths below the surface, as indicated by the water-depth maps, was selected for observation. The depth of the water-table in these villages varied from 9 to 40 ft. No deterioration of land due to salt had been recorded in the selected villages. On inspection it was found that in each village deterioration was in progress, the probable rate of deterioration being 5 per cent of the cultivated area per annum.

A detailed examination was made of the soil conditions in these areas. Pit were dug to the water-table and the soil profiles of both good and deteriorated lands examined. The soil crust was generally 10 ft. in thickness and rested upon a grey sand in which the water-table was situated. The sand below the soil crust had a moisture content of between 4 and 5 per cent down to the water-table. On analysis it was found that in the good land a zone of accumulation of salt was present in the soil crust some distance below the surface. In the deteriorated lands the zone of accumulation of salt was situated within 2 ft. of the soil surface. In no case was salt found in the sand layer. From these observations it was concluded that the salt causing the deterioration was not derived from the water-table and that the rise of water-table was not an essential factor in the formation of a salt efflorescence at the soil surface. Had the salt been derived from the water-table, the zone of accumulation would have appeared only at the surface as in this formation evaporation would produce its maximum effect.

The investigation was now extended to unirrigated areas to determine the natural distribution of salts in the soil crust and the changes which occur in this distribution as the result of the introduction of irrigation. Plots of land which had not received irrigation water were selected, and their soil profiles were examined for salt distribution. Cropping systems were introduced on these plots which represented normal agricultural practice in the Punjab, and the distribution of salt in the profiles was determined after each harvest. An account of this investigation has already been given [McKenzie Taylor, 1938] so that only a brief summary of the results need be presented now.

Figs. 5 and 6 illustrate the effects on salt distribution in the profile resulting from the introduction of irrigation and the growth of cotton and rice. In the case of cotton it will be seen that irrigation has caused a re-distribution of salts originally present in the soil crust. A zone of salt accumulation has been formed similar to that which had been shown to be present in the normal irrigated areas. In the case of rice no zone of accumulation has been formed, but the salt appears to have been washed completely from the soil crust into the underlying sand layer. These observations have important applications to both the prevention of land deterioration and its reclamation.

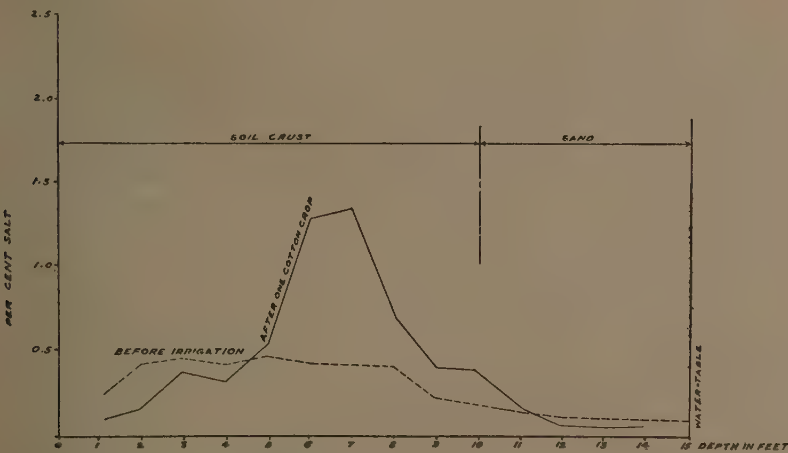

FIG. 5. Distribution of salts before and after a cotton crop at Jaranwala

Having established that a zone of salt accumulation was formed under cotton irrigation, the subsequent history of this zone with different crops was studied. It has been established that if the irrigation water supplied is sufficient to moisten the soil to the depth of the zone of salt accumulation but it is insufficient to balance that lost by transpiration and evaporation, then the tendency is for the zone of salt accumulation to move towards the surface. If the amount of irrigation water is sufficient to counterbalance the losses due to transpiration and evaporation, then the zone of accumulation of salt remains stationary or moves in a downward direction. It seems

therefore that in the Punjab it is necessary to study not only the water requirements of the crops but also the water requirements of the soil with respect to the possibility of deterioration.

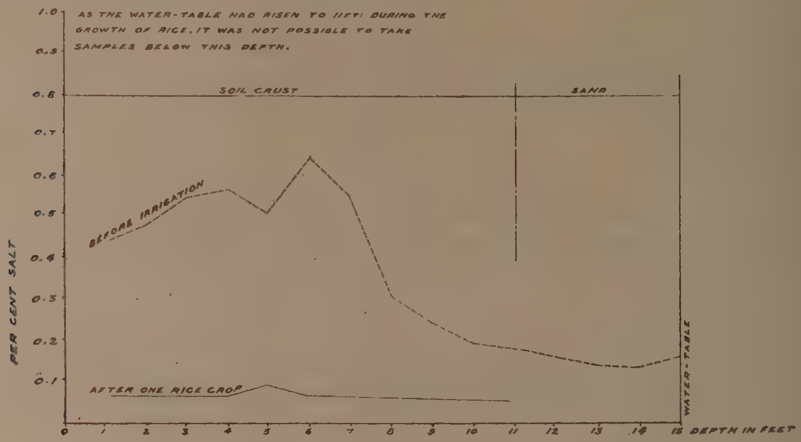

FIG. 6. Distribution of salts before and after a rice crop at Jaranwala

As has been indicated, the water requirements of the soil are of considerable importance. The recognition of this fact led to an examination of the intensity of irrigation in the Lower Chenab Canal area, a portion of the province in which deterioration is taking place at a rapid rate. The intensity of irrigation is the percentage of the culturable commanded area that is irrigated. A diagram illustrating the increase in the intensity of irrigation on the Rakh Branch of the Lower Chenab Canal is given in Fig. 7. From this figure it will be seen that during the last 29 years the intensity of irrigation has continually increased so that the available water is now spread over a much greater area than formerly. Since the general tendency in the area irrigated by the Lower Chenab Canal is for the salts to move towards the surface, it must be concluded that with the present intensity of irrigation the amount of water supplied per unit of area irrigated is insufficient to counterbalance the losses from the soil due to transpiration and evaporation. The increase in the intensity of irrigation is probably due to the increase in population which has been taking place during the last 20 or 30 years, since it is necessary to provide both food and clothing for a greater number of people. The problem has therefore both social and engineering aspects.

From the investigations so far described the essentials of land deterioration in the Punjab appear to be :

1. the presence of salt in the soil crust,
2. the formation of a zone of accumulation of salts in the soil crust with the introduction of irrigation,
3. the intensity of irrigation which determines the position of the zone of accumulation of salts at any time within the soil crust.

The results obtained from the irrigation of rice and illustrated in Fig. 6 are of considerable importance in connection with both the prevention of

land deterioration and the reclamation of deteriorated land. If on the introduction of irrigation rice is the first crop grown, it will be seen that the whole of the salt present in the soil crust can be removed to the underlying sand layer. The results of reclamation experiments to be mentioned later and also investigations in the laboratory have shown that once the salt has been removed from the soil crust to the underlying sand, there is little danger of its return to the soil surface. Deterioration of land containing salts can, therefore, be prevented by the growth of a rice crop in the initial stages of irrigation. At the beginning of a project, when irrigation water is available in large quantities owing to the undeveloped nature of the area, such a practice is possible. With a developed area engineering difficulties, connected with increased channel supplies in the summer while maintaining normal supplies in the winter, are introduced. The solution of the problem of variable supplies, as has been indicated earlier in this paper, is the introduction of modular outlets.

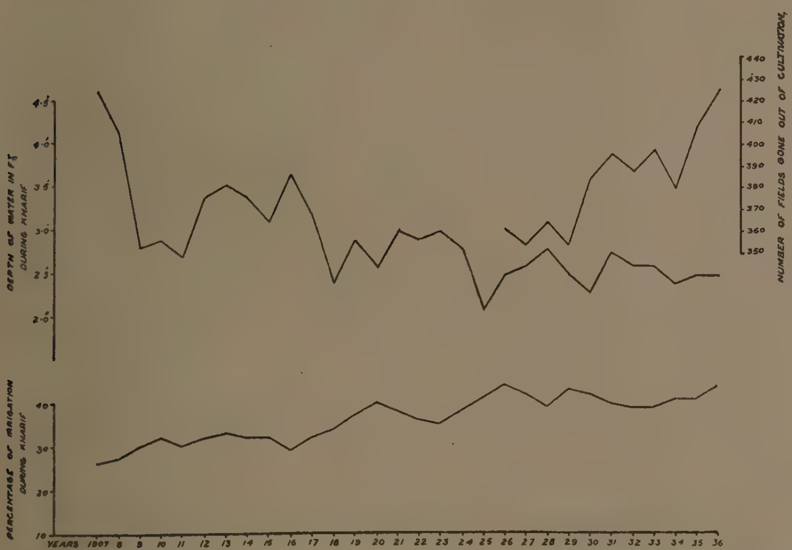

Fig. 7. Curves showing the intensity of irrigation during *kharif*, the delta used during *kharif* and the number of fields gone out of cultivation (Rakh branch, Lyallpur division)

Experiments on reclamation have been in progress for the last nine years. It has been shown that if reclamation is attempted immediately deterioration commences, it can be successfully completed in one year. The longer the reclamation is postponed after deterioration has taken place, the greater is the difficulty experienced owing to the development of increasing alkalinity in the soil. The basis of reclamation, as now practised in the Punjab, is the growth of rice. Before the rice is transplanted the area is leached until the salt content is considerably reduced. The heavy irrigations given during the growth of the rice crop completely eliminate the salt from

the soil crust. The alkalinity which develops on the removal of salt appears to be removed by the action of the roots of the rice plant. The carbon dioxide formed by the roots appears to convert the sodium of the sodium clay into sodium bicarbonate, as indicated by an analysis of the drainage waters. With the removal of alkalinity the soil becomes permeable. It has been shown that, since rice is grown under anaerobic soil conditions, the available nitrogen present in the soil following the rice crop is small in quantity. In order to re-establish the nitrogen balance in the soil a leguminous crop, such as berseem or *senji* (*Melilotus parviflora*), follows rice. A normal rotation of crops is then introduced. The experiments so far carried out have shown that when land has once been reclaimed no deterioration takes place, as indicated by both soil analyses and crop yields, within a period of eight years under the Punjab soil conditions.

During the course of the investigations further interesting observations were made regarding the behaviour of soils in the Punjab containing sodium sulphate. It is characteristic of the Punjab that the salt efflorescence appears in the winter months and disappears in the summer. Sodium sulphate can be present in either the anhydrous or a number of hydrated forms and can go into solution in its own water of crystallization when present in the form of the deca-hydrate. Further, it has been shown by Puri [1937] that soils containing sodium sulphate can abosrb, under certain conditions of humidity and temperature, considerable quantities of moisture from the atmosphere. As a result of this abosrption during a period of high humidity and low temperature, when conditions are again suitable for evaporation to occur a moisture gradient is established in the soil, and there is a tendency for the movement of salt towards the surface. These observations account satisfactorily for the appearance of salts in the winter when humidity and temperature conditions at night are suitable for moisture absorption and in the day-time for evaporation. In the summer period either humidity or temperature or both are unsuitable for moisture absorption by sodium sulphate.

The absorption of moisture by the soils containing sodium sulphate affords an explanation of the zemindar's observations that the best yields of crops are obtained immediately before land goes out of cultivation due to the accumulation of salt. Water is always the main factor limiting crop production in the *rabi* season in the Punjab. If a soil contains sodium sulphate, in an amount insufficient to be directly toxic, water can be abosrbed by the soil up to about 15 per cent by weight. Under these conditions, the crop is unlikely to suffer from water shortage at periods of high atmospheric humidity, and hence the yield of the crop is unlikely to be limited by the water supply factor. Excellent crops of wheat have been observed growing on land during the *rabi* season and the land has gone out of cultivation within a year due to salt efflorescence.

V. Tube-wells

With the completion of the Kalabagh weir which is now under construction on the Indus for the irrigation of the Thal area, the whole of the available supplies of water in the Punjab rivers will be used for irrigation. Considerable

areas remain in which famines occur and for which water is not available. Two courses for the further development of irrigation are open to Government, and both are now under investigation. The first course that may be adopted is the storage of water by means of high dams in the catchment areas. This course is open to objection as in order to fill the reservoir all flood water independent of its silt content will have to be stored. The life of the reservoir under these conditions may not be long. The second course that is open to Government is to install tube-wells driven by electricity. In certain areas this seems to be the more promising line of action to take.

Tube-wells have already been developed to a considerable extent in the United Provinces. At the time of their construction little information was available as to the factors determining design, and the effect of pumping on the stability of the water-table was not considered. An investigation was carried out on the latter subject during the construction period [McKenzie Taylor, 1935]. From a consideration of the monsoon rainfall, the variations in sub-soil water levels as indicated by wells, and the amount of water to be withdrawn from the sub-soil by pumping, it was possible in this case to state, as a result of a statistical examination, that over a period of a climatic cycle the pumping of the water from the tube-wells would be unlikely to affect the stability of the water-table, since the variation in the monsoon rainfall were much greater than the proposed withdrawals, and hence depletion of the water-table in years of low rainfall would be made up in years of high rainfall. The working of the tube-wells in the United Provinces has so far confirmed this prediction.

The rainfall in the eastern portion of the Punjab, for which a tube-well project is being considered, is similar in amount and distribution to that of the United Provinces. An examination of the rainfall and water-table records with reference to the proposed withdrawals is now being carried out. The indications are that in the sub-montane tract of the area there is little danger of the depletion of the water-table.

In the Punjab a factor which militates against the use of the sub-soil water for irrigation is its high salt content. The water is situated in a series of sands which are separated from each other by bands of clay. A considerable number of trial borings have been made and a sample of water from each of the water-bearing sands down to a depth of about 300 ft. has been obtained for analysis. The analysis made to determine the suitability of water for irrigation is based on an investigation which was carried out to determine the concentration of salts in solution which would cause soil deterioration and the ratio of the calcium to sodium content of the water which would prevent base exchange between the soil and the water taking place. As a result of this investigation a formula for the salt-index, by which the suitability of the water for irrigation could be judged, was devised by Puri [1937]. The formula is as follows :—

$$\text{Salt-index} = \text{Total Na} - 24\cdot5 - [(\text{Total Ca} - \text{Ca as } CaCO_3) \times 4\cdot85]$$

All quantities in the above formula refer to parts per 100,000. The salt-index is negative for all good waters and positive for those unsuitable for irrigation. Generally it may be said that waters with a total salt content of under 60 parts per 100,000 are suitable for irrigation, those with a salt content between

60 and 120 parts per 100,000 are suitable if the salt-index is negative, and waters with a salt content above 120 parts per 100,000 are unsuitable for irrigation even though the salt index is negative.

A considerable amount of model work has recently been done to determine the relation between the drawdown and the discharge, the diameter of the strainer and the discharge, and the effect of shrouding on the yield. In order to carry out this work a method for determining the transmission constant of water in sands had to be devised. An account of the method and apparatus used has already been published [Singh, Luthra and Vaidhianathan, 1937].

Fig. 8 illustrates the apparatus used for studying tube-well design. In order to investigate the relation between the discharge and the drawdown, the dimensions of the strainer, the packing of the sub-soil and the depth of water in the well were kept constant. The drawdown was then varied and the discharge for each drawdown was obtained by pumping from the model of the well. In the second portion of the experiment the same data were observed for varying diameters of the strainer and the depth of water in the well. For each case in which the latter two quantities had fixed values, the discharge was plotted as ordinate and the drawdown as abscissa and the plotted points joined by a smooth curve. The curves, showed a more than proportionate increase in discharge for increases in drawdown. It was found that if the first observed point (for the lowest drawdown) was joined to the origin (which automatically lay on the curve as the discharge for a zero drawdown is zero) and the line joining them produced, the other points on the curve were seen to lie above this line. An analysis of the curves by fitting suitable formulæ by statistical methods was carried out. It was shown that the usually accepted linear relationship between Q, the discharge and H, the drawdown $Q=C.H$ was incorrect and the quadratic of the formula $Q=C_1.H+C_2.H^2$ fitted the results within an accuracy of 3 per cent. It was also shown that the coefficient of H increases with the depth of water in the well and with the diameter of the strainer, but doubling the diameter of the strainer only increased the discharge by 12–20 per cent.

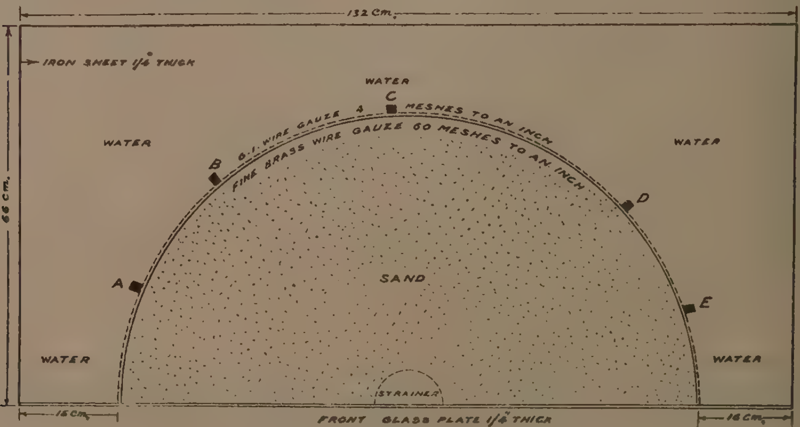

FIG. 8. Tube-well tank.

The conclusions drawn from the model experiments may be stated as follows :—

1. Under field conditions the yield of a tube-well is proportional to the drawdown. If the strainer length is short and the drawdown large, this relation does not hold.

2. The increase in the yield of a tube-well is not proportional to the surface area of the strainer as has generally been accepted. The yield increases very slowely with the increase of diameter.

3. Shrouding may be employed as an alternative to increasing the diameter of the strainer. There is, however, a critical grade of shrouding material for each mean diameter of the water-bearing sands. Increasing the diameter of the shrouding material beyond this point does not increase the discharge of the well, since the main resistance to the flow into the well is from the water-bearing sand.

4. Equal lengths of strainer are more effective if they are situated in deep and continuous permeable strata than if they are in short lengths situated in sands which are bounded by impermeable layers.

The results of these experiments have been applied in the field to the selection of the water-bearing sands from which water should be withdrawn and for determining the size of the strainer to be used. For each bore that has been made samples of the water-bearing sands have been examined for their transmission constants. If the transmission constant, as determined by the apparatus to which reference has been made, is below $0 \cdot 0001$ ft./secs., then the sand is unsuitable as a water-bearing medium for tube-well purposes.

An important point concerning the life of a tube-well has also been under investigation. In the Punjab it has been found that strainers of tube-wells tend to become clogged as a result of the deposition of calcium carbonate on the strainer surface. A series of tube-wells, the history of the discharge of which was known, was examined. The calcium bicarbonate content of the waters derived from these wells was determined. As a result it was shown that if the calcium bicarbonate content exceeded 20 parts per 100,000, then the deposition of calcium carbonate on the strainer was likely to be rapid and the life of the tube-well short. In addition to determining the salt-index of the water obtained from each of the trial bores, the calcium bicarbonate content of the water was also estimated and the suitability of the sand as a site for a tube-well strainer with reference to its length of life was stated in the report.

An examination of a number of tube-wells of varying discharges was made with reference to the handling of the water by the zemindar. The tube-wells ranged in discharges from $1 \cdot 0$ cusec to 5 cusecs. It was found that the zemindar could not handle a five-cusec discharge economically and that such a discharge led to a considerable waste of water. The investigation showed that a tube-well with a discharge of $1 \cdot 5$ cusecs was the most suitable for the irrigation of small holdings such as occur in India.

VI. Distribution of irrigation water and the method of assessment

It has already been stated that a typical canal system consists of a head works, main line, branches, distributaries and minors. In the distributaries and minors, outlets are fixed which discharge into the zemindar's watercourses

and from which the fields are irrigated. In the upper portions of the doabs * the canals are of two types—perennial and non-perennial. Perennial channels run throughout the year, while non-perennial channels are opened on 15 April and are closed on 15 October; in other words, the non-perennial channels irrigate only in summer when the water supply in the rivers is high. The non-perennial channels are, as a rule, situated in the head reach of the canal above the point on the main line where the distribution of the perennial supplies begins. The existence of a number of non-perennial channels in the head reach of the canal is made possible because extra supplies can be run in the main line during summer without affecting the perennial channels lower down. These non-perennial channels in the head reaches of the doabs can be called rice canals, for rice is the most important crop grown in the areas commanded by them.

Instances of non-perennial canals do occur in the lower reaches of the doab. In such cases, although rice still forms a major portion of the cultivation, other crops such as cotton are grown but the area cultivated and the yield obtained is uncertain . On the non-perrennial canals the area irrigated varies between 25 and 40 per cent of the culturable commanded area. The duty of water on these canals is lower than on the perennial channels.

The perennial channels are usually designed to irrigate 75 per cent of the culturable commanded area with a *kharif* to *rabi* ratio of 1 : 2, i.e. they are designed to provide water for 25 per cent of the area in summer and 50 per cent of the area in winter. Lately, however, the cultivators have exceeded the limit of 75 per cent irrigation, although the water supplies in the canals have remained unchanged. This increase in the irrigated area with the same available water supply and its effects will be dealt with in more detail when discussing land deterioration and reclamation.

For the actual distribution of water amongst the cultivators one must consider the supply at the outlet on the distributary and the watercourse. The outlet, as a general rule, is designed to deliver 1·0 to 2·0 cusecs of water, which supply a zemindar can conveniently handle during the course of irrigation. The total area irrigated by any one outlet is called a *chak* and the zemindar is not permitted to carry water from one *chak* to another even though he may be the owner of both the *chaks*. The area which is to be irrigated is divided into squares. Each square is composed of 25 fields of approximately one acre each.

Water in the watercourse is distributed by means of a system of turns called *warabandi*, which is decided upon by the parties concerned and which is sanctioned by the Divisional Engineer in charge of irrigation. *Warabandi* once fixed cannot be changed unless the parties once more agree to do so and obtain the previous permission of the Divisional Engineer.

The unit for the distribution of water is a square of 25 fields. Turns are fixed for each square and the main watercourse is allowed to be breached for irrigating this area at only one point, the situation of which is shown in the records of the engineer in charge. For the further distribution of water inside the square, the zemindar or zemindars dig their own channels and are free to take water to any of the fields within the time allotted to that square. In the

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* Tract of land lying between two rivers.

most commonly practised *warabandi*, a square gets a turn of water every ten days. The regulation of the *warabandi* is controlled by a committee of two or three persons of the village and the village priest, who is provided with a clock and gives the time signal for the change of the turn.

Fig. 10 shows a plan of a typical irrigation system in a Punjab canal colony.

FIG. 9. A portion of the Lower Chenab Canal showing a typical irrigation system.

Scale 1 in. = 7/12 mile.

The system of distribution described above has been evolved as the result of many years of practice and is accepted without question by the zemindars concerned. Difficulties sometimes arise, but these are usually of a temporary nature. For instance remodelling of the distributaries is sometimes necessary on account of silting. This remodelling is frequently accompanied by changes in outlet design which may reduce temporarily the discharges in the watercourses. Since the zemindar knows accurately the area that he can irrigate in a given time, any reduction in this area will be attributed to the remodelling and may be a source of friction between the Irrigation Branch and the zemindar. For some time studies have been in progress with the object of designing an outlet which will give a constant discharge irrespective of the discharge in the parent distributary. At present the Gibb module appears to be the most satisfactory as the fluctuations in discharge into the watercourse do not exceed 5 per cent.

The development of a fixed module is also of considerable importance in connection with land reclamation. In order to reclaim lands additional water supplies must be given. If constant discharge outlets are not fixed, then each outlet will draw a proportion of the increased supply, and as a result the additional water given at the head of a channel will not be available at the reclamation site.

System of water-rate assessment

For the purpose of assessment, the Irrigation Branch appoints revenue officials, called *patwaris*. A *patwari* has a charge of 8 to 10 outlets or irrigation *chaks* and he lives in one of the villages adjoining the *chaks*. He is constantly touring in the area under his charge and maintains a record of all areas irrigated, crops sown, areas matured and areas failed. His work is inspected by the Zilladar and the Deputy Collector and also checked by the Sub-Divisional Officer and the Divisional Engineer.

The charges for irrigation are assessed according to the crops sown, the rates for which have been previously fixed by Government. All fields that have been irrigated are assessed. The rates charged are given in Table I. If the zemindar considers that his crop has failed, he can apply for the remission of the water rate to the Divisional Engineer. A crop is considered as a failure when the yield is less than 25 per cent of that normal for the district. On receiving an application for remission, the Zilladar inspects the standing crop, and if in his opinion the yield is likely to be less than 25 per cent of the normal, the remission is granted.

In order to collect the revenue the *patwari* makes a list of fields irrigated and the crops matured. He prepares an account of the money due from each cultivator and hands a copy of his assessment to the headman of the village with instructions to collect the money and deposit it in the Government treasury. Copies of the accounts prepared by the *patwaris* are forwarded through the Irrigation Department to the Collectors of the various districts, who are ultimately responsible for the Collection of the revenue.

The above method of assessing the revenue is based on the area irrigated and a fixed crop rate. The ideal method for assessment, especially as it would lead to economy in the use of water, would be the volumetric system. In tube-well areas this system has been adopted mainly because it is possible

to measure accurately the volume of water under these conditions. Attempts have been made to introduce the volumetric system on the bigger estates, but so far with little success. Two methods of distribution on the volumetric basis are possible : (1) the contract system in which a guaranteed supply has to be delivered, and (2) that based on the cusec-day which means that the actual volume of water delivered must be paid for. The difficulty in the contract system is that the supplies in the river vary and are below general requirements in *rabi*. It is obviously unfair to the other cultivators to guarantee a supply to one man in periods when water is short. The sale of water by the cusec-day has failed largely because methods of measurements are crude, and devices for measurements can easily be tampered with. Before water can be sold volumetrically accurate measuring instruments must be devised, and they must be of such a robust nature that interference with them becomes impossible.

TABLE I

Schedule of water rates in force on the Lower Chenab Canal

Class	Nature of crops	Rate per acre Rs.	A.	Per
I	Sugarcane (except on non-perennial channels)	11	0	Crop
II	Sugarcane on non-perennial channels	9	0	Do.
III	Water-nuts	7	8	Do.
III A	Rice	6	8	Do.
IV	Indigo and other dyes, tobacco, poppy, spices and drugs	6	4	Do.
IV A	Cotton	5	4	Do.
V	Gardens and orchards and vegetables except turnips	5	8	Gardens and orchards per half year and the rest per crop
VI	Barley and oats (except on non-perennial channels)	4	4	Crop
VI A	Wheat (except on non-perennial channels)	4	4	Do.
VII	Melons, fibres (other than cotton) and all crops not otherwise specified	4	12	Do.
VII A	Maize	4	0	Do.
VIII	Oilseeds (except *rabi* oilseeds on non-perennial channels)	4	4	Do.
IX	*Rabi* oilseeds, barley and oats on non-perennial channels	2	0	Do.
IX A	Wheat on non-perennial channels .	2	0	Do.
X	*Bajra*, gram, *masur* and pulses . .	3	4	Do.

TABLE I—*contd*

Class	Nature of crops	Rate per acre		Per
		Rs.	A.	
XI	*Jowar*, *cheena*, grass which has received two or more waterings and all fodder crops including turnips	2	8	Grass per half year, the rest per crop
XI A	Paddock areas as sanctioned by Local Government	3	0	Per half year on the whole area irrespective of whether it be irrigated in part or whole or not at all
XII	(*a*) Watering for ploughing not followed by a crop in the same or succeeding harvest	1	0	Acre
	(*b*) Village and district board plantation—			
	(1) Any number of waterings in *kharif*	1	0	Half year
	(2) One watering in *rabi* . .	1	0	Do.
	(3) Two or more waterings in *rabi*	2	0	Do.
	(*c*) Grass—A single watering in *kharif* or *rabi*	1	0	Do.

NOTE.—Grass given two or more waterings falls under class XI.

Hemp, indigo and *guara* ploughed in as green manure before 15 September are not assessed to water rates.

A further difficulty in connection with the introduction of the volumetric system which has to be faced by the engineer, though not of engineering origin, is the fragmentation of holdings. It is customary on the death of a zemindar for his estate to be divided amongst the relatives. This leads to a man owning a considerable number of small areas of land scattered over a number of *chaks*. Under these conditions it is impossible to supply water on the volumetric basis. The consolidation of holdings is in progress, and must be completed before the volumetric system of assessment can be introduced.

VII. RAINFALL, RUN-OFF AND SOIL EROSION

These three inter-related elements are of considerable importance in a number of matters with which the engineer has to deal. The relation between rainfall and run-off in the hill areas determines the magnitude and frequency of the floods that may be expected in summer and the seepage back to the river in winter upon which the low river supplies depend. In the plains, the design of drains will depend on the same relationship. The introduction of the soil erosion factor into the relationship determines the silt load of the rivers, which, as has been discussed in the section on canals, affects considerably the entry into canals and hence their costs of maintenance. A further

important effect of the silt load in the river is that, following the construction of a barrage, silt is deposited upstream due to the reduction in the velocity of the water. The building up of the new regime slope of the river upstream of the barrage may lead to considerable flooding of the surrounding areas. An instance of this is afforded by the river Jhelum since the construction of the barrage at Rasul. The town of Jhelum, situated some 25 miles upstream of the barrage is now subjected to flooding with river gauges considerably lower than in the pre-barrage period. Investigations to determine control measures for run-off and soil erosion are, therefore, of the greatest importance.

Gorrie [1939] has made a wide study of this subject in the Punjab from the point of view of disforestation. It is, however, difficult to obtain field data which provide convincing conclusions in this respect.

In order to obtain some information on the subject a small experimental station was established at Nurpur in the foothills of the Himalayas. Six trays were used in these experiments. Each tray had an area of 3,125 sq. cm., and the volume of water which ran off its surface was measured after each shower and expressed as a percentage of the total amount received during the shower. The soil eroded during the shower was weighed and expressed in terms of the soil that would proportionally be eroded from an acre.

Summary of the data

The quarterly averages for the period July 1937-December 1938 are shown in Table II.

TABLE II

Summary of the results of soil erosion and run-off experiments at Nurpur

(July 1937-December 1938)

Period	Total rain (inches)	Mean percentage run-off					
		Trays		Trays		Trays	
		1	2	3	4	5	6
		Grass		Grass	Scrub	Bare	
		Percentage run-offs					
1937 July—September	37·89	20·0	21·2	13·2	19·4	38·1	41·5
October—December	9·72	8·5	25·3	3·1	3·9	38·5	40·3
1938 January—March	10·91	15·8	32·1	7·5	6·6	42·4	51·0
April—June	9·01	15·4	13·3	4·1	10·6	49·7	53·1
July—September	30·31	11·2	12·3	9·1	8·5	60·3	62·0
October—December	0·67	..	..	4·6	1·6	15·5	11·4
Total (18 months)	98·51	15·1	19·2	9·4	12·2	46·4	49·6

TABLE II—*contd.*

Period	Total rain (inches)	Mean percentage run-off					
		Trays		Trays		Trays	
		1	2	3	4	5	6
		Grass		Grass	Scrub	Bare	
		Material eroded (lb. per acre)					
1937							
July—September .	37·89	29·5	36·6	33·1	42·7	169·9	209·4
October—December	9·72	1·5	4·0	0·6	2·4	9·8	12·4
1938							
January—March .	10·91	3·4	4·5	1·5	1·2	9·4	12·3
April—June . .	9·01	3·1	6·0	2·7	3·3	51·9	45·5
July—September .	30·31	3·9	5·5	7·2	4·0	220·2	156·1
October—December	0·67	..	Not measured			..	..
Total (18 months) .	98·51	41·3	56·6	45·1	53·7	461·2	435·7

The above table shows that :

(1) About half the water received as rainfall by a bare surface runs off and does not soak into the soil.

(2) About one-sixth of the water received by grass-covered land runs off its surface, while for land covered with grass and scrub the proportion is only one-tenth.

(3) Trays with similar cover-grass, or grass and scrub, or no cover behave, within limits, in a similar manner.

(4) The different quarters of the year do not markedly affect the percentages of run-off.

(5) There is a gradual increase (leaving the last quarter out when there is little rain) in the proportionate run-off from the bare trays. In the first six months the run-off was about 40 per cent of the water received, in the next six it was very nearly 50 per cent and in the next quarter it jumped to 60 per cent. The covered trays showed no such changes.

(6) The bare trays lose soil, on an average, at about ten times the rate at which grass and scrub covered trays lose it. The latter two types of cover do not appear to be unlike between themselves.

(7) The greatest loss of soil is in the monsoon months whatever be the type of cover.

(8) It is possible for a bare acre of soil to lose, in 18 months, over 20 tons of surface material, while the covered acre loses barely two tons.

An attempt has been made to use the existing rainfall and discharge data for the upper portion of the river Ravi catchment for an examination of the problem in that area. It was hoped that some evidence would be forthcoming regarding the effects of denudation on the discharges of the river in the winter months and also on the number and intensity of floods in the monsoon. No information was available regarding the extent and progress of denudation as no periodical maps had been made to determine the extent of the area affected.

The enquiry was divided into four parts:

(i) A study of the frequency and intensity of floods above 50,000 cusecs recorded during the last 35 years.

(ii) A study of the average winter discharges for the last 20 years, disregarding freshets.

(iii) Analysis of the rainfall records to discover a possible trend towards an increase or decrease in the average monthly values.

(iv) A study of the inter-relation of floods and rainfall.

TABLE III

Distribution and volume of the floods recorded in each year, along with their dates

Year	Date	Discharge (cusecs)	Year	Date	Discharge (cusecs)
1903 (4)	23 July . .	108,000	1910 (5)	29 July . .	116,000
	10 August . .	190,000		1 August . .	85,000
	7 September .	87,000		8 August . .	75,000
	12 September .	83,000		10 September .	60,400
				11 September .	54,200
1904 (1)	6 August . .	57,000			
			1914 (6)	22 July .	51,500
				27 July . .	75,300
1905 (3)	14 July . .	51,000		28 July . .	83,520
	12 August . .	50,000		29 July . .	51,500
	13 September .	85,000		30 July . .	51,500
				7 September .	51,500
1906 (3)	14 September .	73,000			
	15 September .	83,000	1915 (1)	1 August . .	65,250
	16 September .	135,000			
1908 (4)	7 July . .	129,000	1917 (2)	25 September .	89,125
	26 July . .	65,000		27 October .	116,000
	29 July . .	193,000			
	28 August . .	52,000	1919 (2)	25 July . .	73,000
				28 July . .	64,000
1909 (3)	24 August . .	51,000			
	31 August . .	51,000	1920 (2)	23 July . .	129,000
	3 September .	64,000		2 August . .	50,200

TABLE III—*contd.*

Year	Date	Discharge (cusecs)	Year	Date	Discharge (cusecs)
1921	3 August	68,500	1928	28 August	57,774
(3)	13 August	64,000	(2)	2 September	64,000
	22 August	57,400			
			1929	16 August	61,864
1922	26 July	75,150	(1)		
(1)					
			1930	9 April	61,170
1923	16 August	52,867	(4)	11 July	110,625
(1)				3 August	63,750
				9 August	51,500
1924	25 July	116,120			
(2)	28 August	89,245	1932	18 July	168,630
			(3)	23 July	71,570
				27 July	51,126
1925	11 August	94,500			
(2)	13 August	94,500	1933	9 July	101,900
			(5)	22 July	68,686
				23 July	65,168
1926	28 July	61,400		30 July	85,571
(3)	1 August	52,402		14 August	85,100
	30 August	145,000			
1927	4 August	51,134	1936	22 August	192,920
(1)			(2)	23 August	90,820

Total number recorded from 1901 to 1920 =36	Total number from 1921 to 1936 =30
Total number above 100,000 cusecs =8	Total number above 100,000 cusecs =6

This division into two periods of 20 and 16 years showed that there is no noticeable increase either in the number of floods or in their volume within recent years.

Some difficulty was experienced in averaging the figures for earlier years, as the gauge discharge relations were not accurately known. A preliminary analysis was made by noting the number of days in each of the four months from November to February when the supply fell below 2,000 cusecs, and there seemed to be an indication that the number of such days was going up within the last 12 years. But the unreliability of the earlier figures made it difficult to say if the change was real.

The average discharges for the last 20 years were next computed, any values above the usual run of the month being disregarded. These are given in the following table :—

Year	November	December	January	February
1916-17	2,549	2,173	1,931	1,819
1917-18	4,237	2,475	2,361	2,060
1918-19	2,844	2,621	3,340	3,956
1919-20	2,397	2,198	1,998	3,270
1920-21	2,112	1,748	1,976	2,362
1921-22	2,366	2,370	2,954	4,000
1922-23	2,633	2,130	2,972	4,382
1923-24	2,432	2,318	2,211	3,900
1924-25	2,748	2,422	2,445	3,326
1925-26	3,272	2,099	1,852	1,706
1926-27	2,902	1,822	1,682	2,584
1927-28	2,079	1,658	1,939	4,184
1928-29	2,300	2,798	2,751	4,013
1929-30	2,475	4,078	4,200	5,500
1930-31	2,037	1,567	2,073	2,900
1931-32	2,363	1,706	1,705	1,927
1932-33	1,896	1,785	1,822	2,880
1933-34	2,937	2,048	2,249	1,322
1934-35	1,923	1,822	3,051	4,658
1935-36	2,210	1,808	1,692	1,981

The record was too short for any conclusions to be drawn with safety, but it seemed that while a tendency was not established, the winter supplies need to be watched.

The rainfall at Dalhousie was studied both from daily and monthly values. The conclusions drawn from the analysis were :

(*a*) The total monsoon rainfall appears to be steady during the last 14 years. The winter rainfall decreased from 1906 to 1928, after which it has increased. But as the whole period under study amounts to less than the usually accepted cycle of 35 years, these changes which are small are not significant.

(*b*) The records do not show that, within these 35 years, there is any trend towards increase or decrease of precipitation in any individual month.

(*c*) There are, on an average, three to four days during the monsoon months every year when the daily rainfall exceeds 3 in., and about three days in winter months when it exceeds 2 in. The heaviest recorded rainfall (9·8 in.) is for 7 July 1908. This month also recorded the heaviest total rainfall (43·4 in.) and the heaviest rainfall for any four successive days (16·2 in.) for July 26-29.

The inter-relation of floods and rainfall led to the question: Is every flood preceded by unusually heavy rainfall; and conversely, is continuously heavy rainfall followed invariably by a flood?

Some of the heavier floods and the preceding rainfall are shown below :—

Date	Discharge (cusecs)	Rainfall (in.)
29 July 1908 . .	193,000	4·1 (26th), 5·1 (28th) 6·4 (29th)
22 August 1936 .	193,000	6·9 (22nd)
18 July 1932 . .	168,630	3·0 (16th), 3·1 (18th)
10 August 1903 .	190,000	1·1 (7th), 1·7 (8th) 1·0 (9th), 1·8 (10th)
23 July 1920 . .	129,000	3·2 (23rd)
7 July 1908 . .	129,000	9·8 (7th)
30 August 1926 .	145,000	1·1 (29th), 2·5 (30th)
29 July 1910 . .	116,000	1·8 (28th), 3·6 (29th)

The figures for some of the moderate floods registered in succession are shown below :—

Date	Discharge (cusecs)	Rainfall (in.)
22 July 1914 . .	51,500	1·0 (20th), 2·1 (21st), 5·2 (22nd)
27 July 1914 . .	75,300	1·8 (23rd)
28 July 1914 . .	83,520	2·5 (27th)
29 July 1914 . .	51,500	2·1 (28th)
30 July 1914 . .	51,500	5·3 (29th)
14 September 1906 .	73,000	2·8 (14th)
15 September 1906 .	83,000	1·9 (15th)
16 September 1906 .	135,000	3·6 (16th)
11 August 1925 .	94,500	1·2 (9th), 1·5 (10th), 3·2 (11th)
13 August 1925 . .	94,500	3·3 (12th), 3·2 (13th)
22 July 1933 . .	68,686	2·7 (22nd)
23 July 1933 . .	65,168	0·3 (23rd)
22 August 1936 .	193,000	6·9 (22nd)
23 August 1936 .	90,820	2·2 (23rd)

It is thus seen that a heavy flood is usually due either to heavy rainfall on a single day or to moderate rainfall on a successive number of days.

The moderate floods also behave similarly and while the floods in 1933 are heavier for comparatively less rainfall, this may be probably due to a greater intensity of precipitation within fewer hours.

Some of the heavier showers were next examined to see if they were followed by floods :—

Date	Rainfall (in.)	Discharge (cusecs)
22 July 1904 . .	6·9	Rose from 15,000 to 35,000
11 September 1905 .	4·5	Rose from 11,000 (10th) to 17,000 (11th), 24,000 (12th) and 85,000 (13th)
12 September 1905 .	3·5	
13 September 1905 .	4·1	
28 July 1908 . .	5·1	15,000 (27th), 17,000 (28th), 193,000 (29th)
29 July 1908 . .	6·4	
16 August 1909 .	7·3	Gauge rose by 1·8 ft.
24 August 1909 .	6·9	Gauge rose by 6·0 ft. (21,000 to 64,000)
20 June 1917 . .	4·0	Rose from 8,400 (19th) to 30,000 (20th and 21st)
21 June 1917 . .	3·1	
11 August 1925 .	3·2	94,500
12 August 1925 .	3·3	34,200
13 August 1925 .	3·2	94,500
16 July 1932 . .	3·0	37,000 (16th)
18 July 1932 . .	3·1	169,000 (18th)
13 August 1935 .	5·0	22,000 (12th)
22 August 1936 .	6·9	193,000 (22nd)
23 August 1936 .	2·2	90,820 (23rd)

The deductions made were :

(1) The various falls are not strictly comparable, as the intensity of run-off and time-lag have not been allowed for, the distribution of the daily rainfall over all the 24 hours not being known.

(2) There are probably a few showers which would not affect the discharge appreciably, but on the whole the correspondence is satisfactory.

Although it has been impossible to detect any increase in the size or number of floods during the period under examination, this does not mean that

such an increase has not taken place. It appears probable that the denudation had reached its maximum in the period prior to the data examined. It is unfortunate that records of an earlier date are not available.

VIII. Administrative

To conclude this paper with the statement that the object of irrigation is the development of agriculture may seem absurd until it is realized that two separate departments are concerned with the use of the water. The two departments, the Irrigation Branch of the Revenue Ministry and the Agricultural Department of the Development Ministry, are self contained, and each considers the subject from its own particular point of view. The income of the province is the special concern of the Revenue Ministry and to this income the Irrigation Branch is one of its main contributors. The main object of the Irrigation Branch is therefore to produce the greatest possible revenue per cusec of available water. This involves the spreading of the water for irrigation purposes over the greatest possible area. The main object of the Agricultural Department, since it considers the individual zemindar, is the production of the maximum yields of crops per acre. This may involve a larger number of waterings per acre or it may be necessary to grow those varieties of the crops which have long growing periods. Both of these causes necessitate the use of the available water on a relatively small area. Since the basis of assessment is the area under crop and not the volume of water used, it follows that the objects of the two departments are diametrically opposed. It has also been indicated in the section dealing with land deterioration that the increase in the cultivated area without a corresponding increase in the water supply may be one of the factors causing soil deterioration. It will be seen therefore that a major difficulty in obtaining the optimum effect from an irrigation system consists in devising some means of reconciling the opposing objects of the two departments. It has been suggested that since irrigation is for the benefit of the people of the Province, its main object should not be the production of revenue. Where mineral resources are large and industries can be established, this view may hold. When the Province, however, by nature must be mainly agricultural, no alternative source of revenue appears to be available, and therefore it seems likely that the Irrigation Branch will continue to be mainly a revenue-earning department.

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A NEW TYPE OF VARIEGATION IN RICE*

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(With Plate XI and one text-figure)

Introduction and review of literature

SEVERAL types of chlorophyll deficiencies in rice have been described and genetically studied. They include both unicoloured and variegated forms which are inherited either as a result of the operation of genetic factors or as a result of the transmission of abnormal plastids contained in the cytoplasm of the egg-cells. All the unicoloured types, so far studied, are known to be inherited in a mendelian fashion ; they are usually recessive to normal green and are controlled by one or more pairs of factors. Thus Morinaga [1927], Ramiah [1930], Kadam and Patanker [1934], Codd [1934] and others have shown that one, two or three pairs of recessive factors when present in the homozygous condition produce albinos. Other unicoloured seedlings variously described as virescent, xantha, lutescent, etc., have also been shown to be inherited on mendelian lines [Ramiah and Ramanujam, 1935].

Variegated plants may be divided into two classes : those that exhibit variegation in the early seedling stages, becoming green later on, and those that continue to show the variegation up to maturity. Among the former may be mentioned the striped seedlings reported by Ramiah and Ramanujam [1935] and Jodon [1940] ; these are also inherited on mendelian lines. Variegated plants described by Kondo *et al.* [quoted by Imai, 1928], Morinaga [1932], Mitra and Ganguli [1934], Ramiah and Ramanujam [1935], and Oryozi [1936] belong to the latter class. In most of the above-mentioned cases the variegation occurs in coarse, longitudinal stripes of green and yellow or green and white on the stem, foliage, leaves and glumes ; all the tillers of the plant may be variegated or occasionally a few green tillers may be found on a variegated plant, or *vice versa*. In some cases the variegation may consist of fine stripes of white and green and individuals of this type are variegated in all their tillers. Apparently the type of variegation described by Mitra and Ganguli [1934] belongs to this class.

As regards inheritance, variegated plants are inherited either bi-parentally or maternally. Mitra and Ganguli [1934] obtained pure white-striped plants which behaved as a simple recessive to normal green. Morinaga [1932] has also recorded the simple inheritance of a few variegated forms. The variegated plants described by the other authors all show maternal inheritance. These may again be divided into two classes in regard to hereditary type : in

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GREEN VARIEGATED

Fig. 1 Green and variegated seedlings showing stripes in the latter

GREEN VARIEGATED

one case variegated plants appear in great numbers in the progeny of these plants, and in the other few or no variegateds are obtained, but segregation produces green and white seedlings from green-and-white variegated plants and green and yellow from green-and-yellow variegated plants; the white and yellow seedlings die after a few days in the nursery. The appearance of a large number of variegated plants in the progenies of such plants is explained by Imai [1928] to be due to the habitual mutability of the plastids, entirely out of control of genetic factors.

It is obvious from the foregoing review of literature that inheritance of variegation in rice is either maternal or bi-parental. In this paper a new type of variegation is described which combines both these types of inheritance.

Description and breeding behaviour of the variegated plant

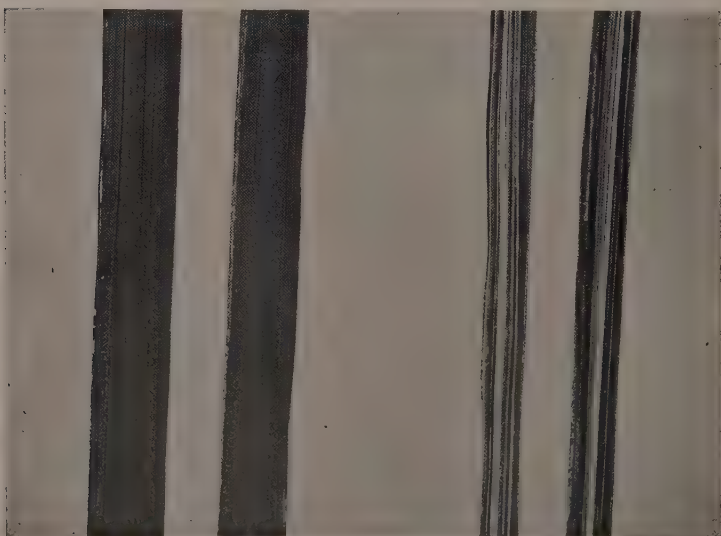
In the year 1934-35 one variegated seedling was noticed in the seedbed of the rice variety Imperial Pusa 27 at the Botanical Section in Pusa. The leaves of this plant showed fine longitudinal stripes of green and white, and this striping was noticed to persist in all the tillers of the plant even at maturity (Plate XI, figs. 1 and 2). The glumes were mostly white or occasionally striped. This plant differed from those described by Ramiah and Ramanujam [1935] in that the variegation was not as coarse and variable as in the latter, and, furthermore, no green tillers were produced on this plant. The plant was weaker than its sisters, the leaves were narrower and rolled inwards from the margin and seed-setting was poor. The seeds of this plant, when sown the following year, gave rise to variegated plants resembling the mother and albinos which died a few days after. The progenies of some of these variegated plants were studied in 1937-38 and the segregations observed are given below :–

Variegated plant No.	Nature of progeny		Variegated plant No.	Nature of progeny	
	Variegated	Albino		Variegated	Albino
1 . . .	18	17	15 . . .	84	31
2 . . .	31	42	16 . . .	33	19
3 . . .	78	41	17 . . .	16	25
4 . . .	23	8	18 . . .	4	2
5 . . .	3	1	19 . . .	19	12
6 . . .	27	30	20 . . .	20	7
7 . . .	60	47	21 . . .	52	17
8 . . .	70	65	22 . . .	18	8
9 . . .	39	12	23 . . .	8	4
10 . . .	26	22	24 . . .	60	30
11 . . .	38	26	25 . . .	13	9
12 . . .	5	31			
13 . . .	23	26		795	548
14 . . .	25	16			

It is seen from the above table that the variegated plants give rise to variegateds and albinos in varying proportions, and that no green plants are present in any progeny. In this respect the variegated plants resembled

GREEN VARIEGATED

FIG. 1 Green and variegated seedlings showing stripes in the latter



GREEN VARIEGATED

FIG. 2 Mature leaves of green and variegated plants

one case variegated plants appear in great numbers in the progeny of these plants, and in the other few or no variegateds are obtained, but segregation produces green and white seedlings from green-and-white variegated plants and green and yellow from green-and-yellow variegated plants; the white and yellow seedlings die after a few days in the nursery. The appearance of a large number of variegated plants in the progenies of such plants is explained by Imai [1928] to be due to the habitual mutability of the plastids, entirely out of control of genetic factors.

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5 . . .	3	1	19 . . .	19	12
6 . . .	27	30	20 . . .	20	7
7 . . .	60	47	21 . . .	52	17
8 . . .	70	65	22 . . .	18	8
9 . . .	39	12	23 . . .	8	4
10 . . .	26	22	24 . . .	60	30
11 . . .	38	26	25 . . .	13	9
12 . . .	5	31			
13 . . .	23	26		795	548
14 . . .	25	16			

It is seen from the above table that the variegated plants give rise to variegateds and albinos in varying proportions, and that no green plants are present in any progeny. In this respect the variegated plants resembled

the maternally inherited types described by Kondo, the only difference being that in the latter case a few green plants were also found to occur in the progenies of variegated plants.

In the following year (1938-39), several variegated plants were again grown and their progenies were found to segregate into variegateds and whites in varying proportions as on previous occasions. One plant, however, gave rise to a few greens besides whites and variegateds. One hundred seeds of one of these green plants were sown in 1939-40 and the resulting seedlings showed a segregation of 70 green to 20 variegated ; there was not a single albino present. This segregation seemed to indicate a monohybrid ratio with variegation as recessive to green.

To confirm these results eleven green plants from this segregating culture were selected at random and crossed reciprocally with variegated plants during 1939-40. The setting in crosses and the variegated plants was poor as the latter is normally a poor setter. The seeds from the parents and the crosses were sown in 1940-41. The following are the results :—

Segregation in the progenies of green plants

Culture No.	Green	Variegated	Total	Remarks
G 20	98	*Nil*	98	
G 254	95	*Nil*	95	One hundred seeds in each culture were sown.
G 134	98	*Nil*	98	
Total .	201	..	300	
G 251	80	18	98	
G 124	73	20	93	
G 171	78	20	98	
G 70	70	29	99	
G 128	77	22	99	
G 131	76	21	97	
G 23	70	29	99	
G 230	66	25	91	
Total .	590	184	774	
Calculated 3 : 1 . . .	580	194	774	

P between 0.5 and 0.3. Therefore the fit is good.

It is seen from the above table that out of 11 families in the F_3 (assuming the original green plant to be a natural cross) three were pure for green and eight segregated into green and variegated in the ratio of 3 : 1. These figures amply confirm the earlier finding that variegation itself is a simple recessive to normal green.

The variegated plants used as parents in the artificial crosses set very few seeds, and they, on sowing, gave rise to striped and white plants as expected.

Segregation in artificial cross progenies

Parents of the crosses	No. of seeds obtained from the cross	No. of seeds germinated	Nature of progeny		
			Green	Variegated	White
Variegated 12 × homozygous green 254	1	1	1	..	..
„ 1 × „ 20	2	1	1	..	..
„ 16 × „ 134	1	..	..	..	..
Total	4	2	2	..	..
Variegated 15 × heterozygous green 70	3	3	3	..	..
„ 21 × „ 131	8	6	2	3	1
„ 1 × „ 23	6	2	2	..	..
„ 10 × „ 128	2	..	..	..	..
„ 15 × „ 131	1	1	..	1	..
„ 27 × „ 251	6	6	2	..	4
Total	26	18	9	4	5
Heterozygous green 171 × variegated 1	4	4	3	1	..
„ 230 × „ 1	4	..	..	..	..
Total	8	4	3	1	..

Unfortunately, in the above crosses the seed-setting was poor and only very few F_1 plants were obtained. Nevertheless an examination of the progenies obtained from these crosses confirms the fact that variegation itself is a genetic character being inherited as a simple recessive to green, while albinism is transmitted only maternally.

The expected behaviour of the parents and crosses on the basis of this combined inheritance may be schematically represented as in Fig. 1.

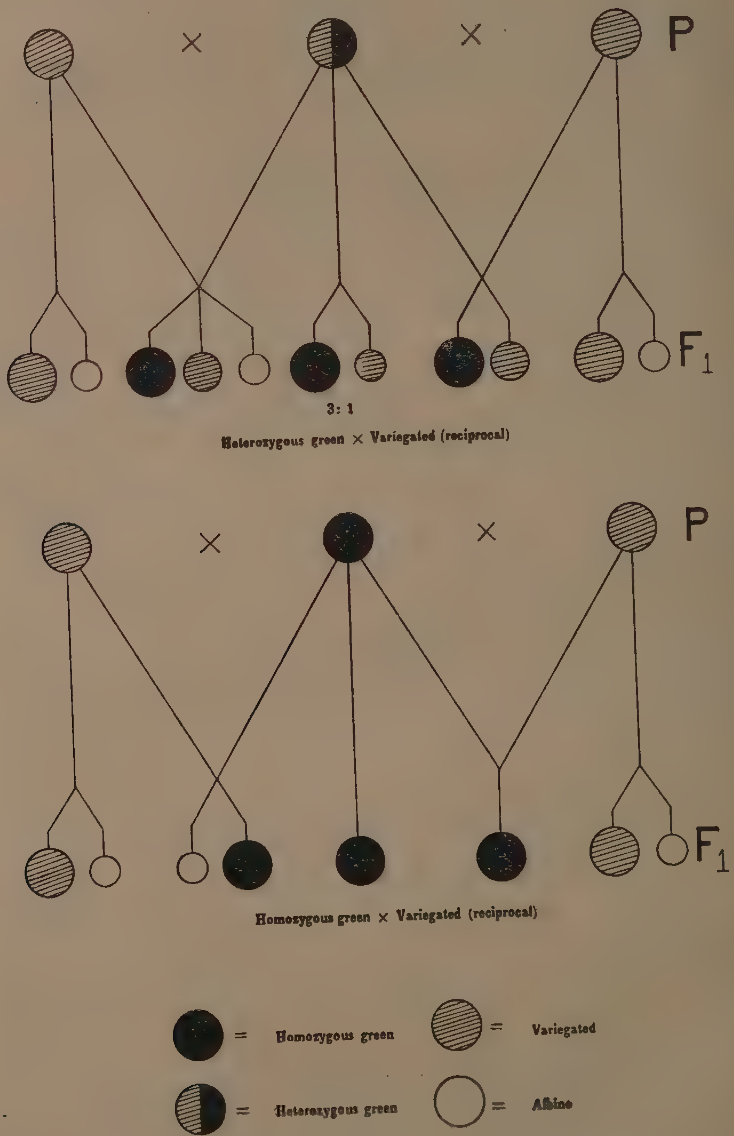

Fig. 1. Expected behaviour of parents and crosses

When the actual data obtained are examined in the light of this scheme, it is found that the expectations are mostly fulfilled, except in the case of crosses between homozygous green × variegated which, unfortunately, did not set any seed.

Discussion

The important point to notice about the variegation described here is that, unlike the case in coarsely variegated plants, its pattern is fairly constant through successive generations; it does not produce any wholly green tillers. The only variegated type that might be related to this is the one described by Mitra and Ganguli, but in the latter case the inheritance is governed by a 'pattern gene' and pure variegateds are obtained. The only reported case, as far as we know, of a variegation which is inherited as in the present case is that reported in barley by Sô in 1921 (quoted by Imai [1928]). This variegated race is described to have fine white stripes on foliage and ears. Sô studied thoroughly the genetic behaviour of variegation in this variety and found that albinism was transmitted only maternally, while variegation itself was a mendelian recessive to green. On the basis of these experimental facts he developed a theory to account for the special hereditary bevahiour of his barley. According to him the variegated character, which is transmitted as a recessive, is not due to a pattern gene since the white parts of stripes are due to the distribution of white plastids which have changed their quality permanently and, therefore, are able to give rise to albinos in the progeny of variegated plants. 'The variegation is, therefore, produced by a factor which alters at times the essential quality of the plastids from normal green to colourless'. The plastid mutation that is observed in various other plants is due to sporadic events, but in the case of this barley and the present case in rice, the plastid mutation repeats itself so frequently in the course of the development of the plant body that not a single individual or leaf or even an ear is free from variegation. This presumably accounts for the constancy of this character from generation to generation.

Although some of the results of crosses are still incomplete, and we are continuing the investigation, the results so far obtained amply confirm the peculiar nature of inheritance of variegation reported in this paper.

Summary

A new type of variegation is described. The variegated plants have fine stripes of green and white on the stem, foliage and glumes. They are weaker than the green plants, with narrower leaves and poorer seed-setting.

The variegated plants, when selfed, give rise to variegated plants and albinos in varying proportions; but when crossed reciprocally with green plants, give rise to normal greens in the F_1 generation. Heterozygous green plants segregate into greens and variegateds in the ratio of 3 : 1; no albinos are present in the progenies.

The breeding behaviour of variegated plants in selfed and crossed progenies has shown that variegation is a mendelian recessive to green, but albinism is transmitted only maternally.

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FIBRE-MATURITY IN RELATION TO GROUP-LENGTHS OF SOME COTTONS GROWN IN THE PUNJAB

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(With three text-figures)

I. Introduction

THE spinning performance of a cotton depends upon the physical characters of the individual fibres composing it, such as length, fineness, width, strength and maturity. The importance of these characters in assessing the value of a cotton is realized when it is brought out that for Indian cottons [Turner and Venkataraman, 1933] the total correlation coefficients between the highest standard warp counts (H. S. W. C.) and each of the first four of these characters are :

H. S. W. C. and mean fibre-length	+0·87
H. S. W. C. and mean fibre-weight per unit length . .	—0·80
H. S. W. C. and mean fibre-width	—0·69
H. S. W. C. and mean fibre-strength	—0·33

and are all of them significant for $P \geq 0 \cdot 05$. For 32 samples of Indian cottons Gulati and Ahmad [1935] find the correlation coefficient between the H. S. W. C. and the percentage of mature fibres to be —0·07. Examining further they find that, for comparatively short-staple cottons, higher spinning performance is associated with lower maturity percentage and that, for medium-staple cottons, higher fibre-maturity goes hand-in-hand with better spinning performance. The correlation coefficient between the percentage of mature fibres and H. S. W. C. for the first group comes out to be —0·66, while that for the second group is found to be +0·56. The coefficient for the first group bears a negative sign while that for the second group is positive. Thus 'in a batch of cottons containing short-staple and medium-staple samples the opposite trends cancel one another, resulting in an insignificant correlation between the two attributes'.

This conclusion is very important as it contains the germ of the idea on which some previous studies as well as the present one in the technology of Indian cottons are based. Any sample of cotton contains fibres of different lengths and it is known that the physical characters of fibres of different lengths even of the same cotton may vary from one group-length to another. Turner [1929] concluded that in some cottons differences did exist in the fibre-weight

per unit length for different lengths of fibre. Iyengar and Turner [1930], from a study of 18 standard Indian cottons, including all the important commercial types, concluded that the fibre-weight per unit length was not the same for different lengths of fibre of a given cotton. Nanjundayya and Ahmad [1938] found that the mean breaking load and fibre-weight per unit length decreased with an increase in group-length for all the Indian cottons excepting N 14 which behaved somewhat erratically. Iyengar [1939] concluded that the mean and maximum ribbon-width and the swollen diameter generally decreased with increase of length and that variations in the number of convolutions per unit length and in the maturity of fibres with respect to length were different in different cottons.

The importance of the study of fibre-maturity in a cotton has been stressed by Gulati and Ahmad [1935], and it is seen from the above summary of previous work that variations in fibre-maturity with group-length have not systematically been studied heretofore. The work described in the present paper was undertaken with the object of studying these variations in the Punjab cottons.

II. Material

The material for this work was drawn from the bulk samples of the seed multiplication area at the Cotton Research Farm, Risalewala, Lyallpur, in 1937. The varieties were :

Punjab-*desi*	39 Mollisoni
New crosses	Jubilee
Punjab-American	289F, 289F/43, 289F/K25, 4F, LSS, 47F, 58F, 100F and 104F

The sliver for each variety was obtained by the usual sampling methods and constituted the working sample.

III. Experimental

Each variety was tested for quality of the bulk sample with reference to the following fibre characters :—

(*a*) Mean length

(*b*) Modal length

(*c*) Fibre-length irregularity percentage

(*d*) Mean fibre-weight per unit length

and (*e*) Immaturity.

The mean length was determined with Balls Sledge Sorter and the modal length and fibre-length irregularity percentage were derived from the Balls sorter distribution by the methods described by Ahmad [1932]. The mean fibre-weight per unit length was obtained after the whole-fibre method and fibre immaturity was determined by the technique described by Gulati and Ahmad [1935] using the 'maturity slides' devised by Ahmad and Gulati [1936]. The values thus obtained for the bulk sample are given in Appendix I.

The sliver of each variety was then fed into the feed-box of the Balls Sledge sorter and the fibres laid on the one-way plush and collected in groups of $\frac{1}{8}$th of an inch as is usually done in a Balls sorter test. By repeating the process, sufficient quantity of fibre was collected in each group-length. The bundle of fibres in each group-length was hand-drafted, cleaned and combined to give a hand-made sliver. The different slivers were kept separate from one another in paper wrappers with distinct markings indicating the group-lengths. The fibres in each group-length were tested for maturity. For this purpose, it was found that the 'maturity slides' of Ahmad and Gulati were very convenient for mounting fibres in group-lengths of 5/8 inch and above. For fibres in group-lengths of 4/8 inch and lower, the following method was improvised :

A microscope-slide was sparsely wetted with water and the fibres, taken individually from the sliver with a pair of forceps, were arranged in the middle part of the slide as nearly parallel to one another as possible and with one of their ends approximately along a line. After placing a sufficient number of fibres on the slide, a cover-glass slip, with a drop of 18 per cent caustic soda solution adhering to it, was slid on to the slide such that the fibres were held between the slide and the cover-slip by the caustic soda solution. Fifteen minutes later the slide was examined for maturity.

This technique was also adopted for fibres of the longest group-length of each variety as there were only a few fibres in that group.

The number of fibres tested for maturity was not less than 500 [Gulati and Ahmad, 1935] in each group-length excepting the end ones, where, due to a deficiency in the number of fibres, all the fibres collected were tested. The results of these tests are given in Appendix II, which contains both the actual numbers and percentages of mature, half-mature and immature fibres as well as the total number of fibres tested in each group-length of the different varieties.

IV. Discussion of results

As the percentage of mature fibres in a sample determines, to some extent the behaviour of the sample, during spinning processes, the statistical analysis of the results was carried out on the percentage of mature fibres in each group-length. To study the influence of the half-mature and the immature fibres present in each group-length, the statistical analysis was repeated on the 'maturity coefficient' in each group-length of these varieties. This coefficient was derived according to the formula given by Peirce and Lord [1934] and served to express the result of the maturity count as a single quantity suited to quantitative analysis. (The percentage of mature fibres and the maturity coefficient are collectively referred to hereinafter as maturity 'terms' for simplicity.)

(*a*) The number of *desi* cottons tested was only two. Of these, 39 Mollisoni is an indigenous cotton and Jubilee is a new cross between the Punjab-Mollisoni and the Chinese Million Dollar. No general conclusions could be drawn from such meagre data, but a study of the results showed that, in 39 Mollisoni, both the percentage of mature fibres and the maturity coefficient remained almost constant in all the group-lengths with the exception of the

first group (i.e. 2/8 inch), while in Jubilee, both these terms showed an increase with an increase in the group-length.

(*b*) The other varieties were all Punjab-American (P-A) cottons, with staple-lengths ranging between 2·21 and 2·43 cm. with the exception of P-A 4F, which had a staple-length of 1·92 cm. and was not, therefore, included in the analysis.

Table I

Maturity terms

Group length	289F	289F/43	289F/K 25	58F	100 F	104F	L S S	47F	Average
					(a) Percentage of mature fibres				
3	76·2	47·5	43·2	69·7	64·3	47·0	62·5	58·9	58·66
4	75·0	38·6	39·6	65·0	57·7	41·0	61·7	54·6	54·15
5	62·9	42·6	40·0	62·3	48·5	51·6	57·9	50·7	52·06
6	67·1	39·1	35·6	67·6	58·8	50·3	54·1	60·5	54·14
7	71·4	35·7	31·1	66·4	57·2	45·6	51·3	56·3	51·88
8	69·6	43·5	35·8	73·4	54·4	52·8	53·4	48·1	53·88
9	67·4	47·3	47·8	78·0	57·6	47·8	52·4	47·6	55·74
10	70·8	50·2	43·6	76·9	63·4	60·0	69·2	59·2	61·66
Average	70·05	43·06	39·59	69·91	57·74	49·51	57·81	54·49	55·27
					(b) Maturity coefficient				
3	0·9198	0·8071	0·7797	0·8971	0·8717	0·7958	0·8663	0·8561	0·8492
4	0·9234	0·7710	0·7844	0·8813	0·8586	0·7718	0·8637	0·8492	0·8379
5	0·8814	0·7896	0·7539	0·8853	0·8145	0·8128	0·8478	0·8374	0 8278
6	0·8940	0·7722	0·7620	0·9023	0·8574	0·8167	0·8437	0·8606	0·8386
7	0·9043	0·7733	0·7547	0·9050	0·8606	0·8048	0·8387	0·8562	0·8372
8	0·9091	0·8055	0·7861	0·9219	0·8619	0·8358	0·8419	0·8354	0·8497
9	0·9027	0·8209	0·8088	0·9346	0·8744	0·8338	0·8584	0·8304	0·8580
10	0·9183	0·8437	0·8165	0·9334	0·8918	0·8764	0·9018	0·8763	0·8823
Average	0·9066	0·7979	0·7808	0·9076	0·8614	0·8185	0·8578	0·8502	0·8476
					(c) Maturity index				
3	0·8530	0·6554	0·6116	0·8124	0·7694	0·6395	0·7593	0·7398	0·7300
	0·8562	0·5923	0·6119	0·7834	0·7410	0·5974	0·7544	0·7233	0·7075
5	0·7801	0·6238	0·5718	0·7843	0·6669	0·6697	0·7270	0·7011	0·6906
6	0·8039	0·5948	0·5754	0·8158	0·7412	0·6728	0·7152	0·7483	0·7084
7	0·8246	0·5905	0·5580	0·8173	0·7428	0·6490	0·7038	0·7354	0·7027
8	0·8281	0·6465	0·6078	0·8515	0·7399	0·7023	0·7116	0·6941	0·7227
9	0·8159	0·6733	0·6828	0·8760	0·7619	0·6915	0·7377	0·6866	0·7407
10	0·8423	0·7087	0·6615	0·8727	0·7948	0·7686	0·8178	0·7671	0·7792
Average	0·8255	0·6357	0·6101	0·8267	0·7447	0·6739	0·7409	0·7245	0·7227

TABLE II

Analysis of variance

Source of variation	D. F.	Sum of squares	Mean square	F	Remarks
(a) Percentage of mature fibres					
Varieties . .	7	6993·04	999·01	51·205	H. S.
Length-grades . .	7	631·11	90·16	4·621	H. S.
Residual . .	49	955·99	19·51	..	..
Total .	63	8580·14	..	..	..
(b) Maturity coefficient					
Varieties . .	7	0·121352	0·017336	71·17	H. S.
Length-grades . .	7	0·015925	0·002275	9·34	H. S.
Residual . .	49	0·011934	$0{\cdot}000243_6$	..	..
Total .	63	0·149211	..	..	..
(c) Maturity index					
Varieties . .	7	0·358720	0·051246	64·14	H. S.
Length-grades . .	7	0·043494	0·006213	7·776	H. S.
Residual . .	49	0·039130	0·000799	..	..
Total .	63	0·441344	..	..	..

In the six varieties, 289F, 289F/43, 289F/K25, 58F, 100F, and 104F, the percentages by weight of fibres in the two pairs of end-groups, viz. the 2/8, 3/8, and the 10/8, 11/8 inch groups, as determined with the Balls sorter, were very small. Therefore, the average of the maturity terms of the first pair of end-groups was taken as representative of the 3/8 inch group and that of the second pair as representative of the 10/8 inch group. The varieties L S S and 47F did not have fibres longer than 10/8 inches in length. Hence the maturity terms only in the first pair, viz. 2/8 and 3/8 inch groups, were averaged, the average being considered as belonging to the 3/8 inch group. The values in the 10/8 inch group remained unaltered. The values of the maturity terms thus formed are compiled in Tables I (*a*) and (*b*) and the analysis of variance is brought out in Tables II (*a*) and (*b*) respectively.

The analysis of variance applied to these results showed that the mean square due to varieties was highly significant for both the maturity terms as was naturally to be expected. The mean square due to length-grades was also highly significant showing that, in addition to differences in fibre-maturity

brought about by differences in variety, there was an intrinsic variation in fibre maturity with a variation in the length of the fibre. This latter variation could best be studied by fitting a curve between the group-length and the corresponding average maturity term. Parabolic regression equations were fitted by Fisher's covariance-matrix method which was described in detail by Koshal [1934]. The utility of this method is evident from the fact that the same covariance-matrix has been used for deriving the equations I and II for the percentage of mature fibres and the maturity coefficient respectively. Moreover, it provides material for the calculation of the standard error of the regression coefficients.

The two regression equations were :

$$M = 75\cdot734 - 7\cdot681\ l + 0\cdot620\ l^2 \quad . \quad . \quad . \quad . \quad . \qquad \text{I}$$

and $$C = 0\cdot9061 - 0\cdot02661\ l + 0\cdot002410\ l^2 \quad . \quad . \quad . \quad . \qquad \text{II}$$

where M is the percentage of mature fibres ;

C is the maturity coefficient [Peirce and Lord, 1934] ; and

l is the length-grade in units of one-eighth of an inch.

The standard errors of the regression coefficients were :—

$$\left.\begin{array}{l} -7\cdot681 \pm 1\cdot284 \\ +0\cdot620 \pm 0\cdot0975 \end{array}\right\}\text{equation I ;}$$

and $$\left.\begin{array}{l} -0\cdot0266 \pm 0\cdot0041 \\ +0\cdot00241 \pm 0\cdot00031 \end{array}\right\}\text{equation II.}$$

TABLE III

Further analysis of variance

Source of variation	D. F.	Sum of squares	Mean square	F	Remarks
		(a) Percentage of mature fibres			
Parabolic regression .	2	566·36	283·18	..	..
Deviations from regression	5	64·75	12·95	0·66	N. S.
Total (length-grade)	7	631·11	..	..	..
		(b) Maturity coefficient			
Parabolic regression .	2	0·015293	0·007647	..	..
Deviations from regression	5	0·000632	0·0001264	0·52	N. S.
Total (length-grade)	7	0·015925	..	..	..
		(c) Maturity index			
Parabolic regression .	2	0·041694	0·020847	..	...
Deviations from regression	5	0·001800	0·000360	0·45	N. S.
Total (length-grade)	7	0·043494	..	..	..

Regression equations:

$$M = 75{\cdot}734 - 7{\cdot}681\ l + 0{\cdot}620\ l^2 \quad . \quad . \quad . \quad . \quad . \qquad \text{I}$$

$$C = 0{\cdot}9061 - 0{\cdot}02661\ l + 0{\cdot}00241\ l^2 \quad . \quad . \quad . \quad . \qquad \text{II}$$

$$MI = 0{\cdot}8342 - 0{\cdot}04834\ l + 0{\cdot}004269\ l^2 \quad . \quad . \quad . \quad . \qquad \text{III}$$

where M is the percentage of mature fibres
C is maturity coefficient,
MI is maturity index, and
l is length-grade in units of one-eighth of an inch.

TABLE IV

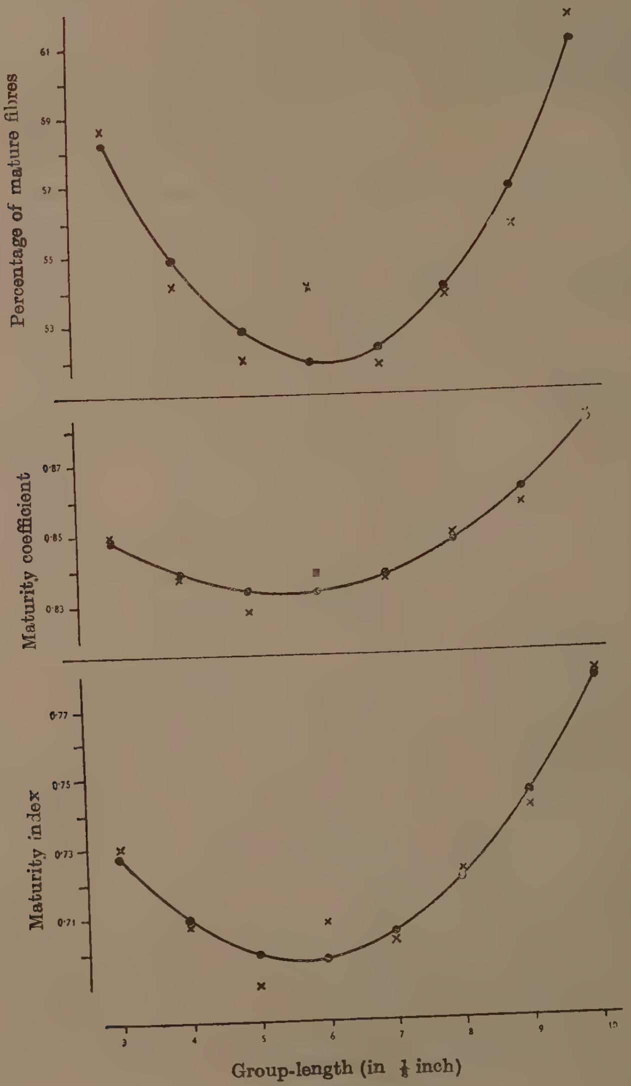
Observed and calculated values of maturity terms

l	M		C		MI	
	Observed	Calculated	Observed	Calculated	Observed	Calculated
1	2	3	4	5	6	7
3 . .	58·66	58·27	0·8492	0·8480	0·7300	0·7276
4 . .	54·15	54·93	0·8379	0·8382	0·7075	0·7091
5 . .	52·06	52·83	0·8278	0·8333	0·6906	0·6992
6 . .	54·14	51·97	0·8386	0·8332	0·7084	0·6978
7 . .	51·88	52·35	0·8372	0·8379	0·7027	0·7050
8 . .	53·88	53·97	0·8497	0·8475	0·7227	0·7207
9 . .	55·74	56·82	0·8580	0·8618	0·7407	0·7449
10 . .	61·66	60·92	0·8823	0·8810	0·7792	0·7777

The regression coefficients were all statistically significant to one per cent level, thus giving further proof of the reality of the variation of fibre-maturity with fibre-length. In a further analysis of variance (Tables III *a* and *b*) the sum of squares due to length-grades with seven degrees of freedom was split up into two components, the first due to the fitting up of the parabolic regression equation with two degrees of freedom and the second due to deviations from the regression equation with five degrees of freedom. The mean square due to deviations from the regression equation was non-significant, showing that the regression equation of the second degree fitted the observed data very well and completely explained the variation in fibre-maturity with fibre-length.

In columns 2, 3 and 4, 5 of Table IV are given the observed values of the two maturity terms alongside the values obtained from equations I and II respectively for comparison. These values are plotted in the form of curves

in Figs. 1 and 2, where each curve shows the value obtained from the equation, while the crosses indicate the values obtained experimentally. The agreement between the observed and the calculated values will be seen to be very close.



FIGS. 1, 2 and 3

As was observed early in this paper, Gulati and Ahmad [1935] find that in a number of Indian cottons with a fairly wide range of fibre properties, the

correlation coefficient between fibre-maturity and H. S. W. C. is non-significant. Further study indicated that the correlation between spinning value and percentage of mature fibres was negative for short-staple cottons and positive for medium and long-staple cottons. From a study of Figs. 1 and 2, it will be found that as group-length increases from $\frac{3}{8}$ to $\frac{6}{8}$ of an inch, both the percentage of mature fibres and the maturity coefficient decrease continuously. For this part of the curve, the correlation between each of the maturity terms and group-length is negative. The nadir of the curve is reached when the group-length is $\frac{6}{8}$ of an inch. Thereafter, a further increase in group-length is accompanied by a corresponding increase in the maturity terms, so that for this part of the curve the correlation between the two variables is positive.

The total correlation coefficient between fibre-length and H. S. W. C. is as high as $+0 \cdot 87$ [Turner and Venkataraman, 1933]. It is, therefore, natural to expect that the relation between fibre-maturity and group-length shall be similar to that between fibre-maturity and H. S. W. C. Hence the above conclusion confirms that arrived at by Gulati and Ahmad from quite different considerations altogether.

While this paper was under preparation, an article by Hawkins [1938] appeared on a study very similar to the one under report. Thirty-one samples of Acala seed-cotton were each analysed into different length-grades with a Pressley [1933] sorter. The pairs of length-grades 4/8 and 5/8, 6/8 and 7/8, and 8/8 and 9/8 inch were each bulked and the four groups thus obtained, together with the 10/8 inch length-grade, were tested for maturity by the Shirley Institute method (which is essentially the same as that used in this study). The data obtained in each group for fibre-maturity were converted into a single factor, called the 'maturity index', by the formula :

$$(MI) = \frac{(10m + 5t + i)}{10N}$$

where (MI) is the maturity index ;

m is the number of mature fibres ;

t is the number of intermediate fibres ;

i is the number of immature fibres ; and

N is the total number $(m + t + i)$ of fibres in the sample.

(In Hawkins' paper, the denominator on the right-hand side of the formula is given incorrectly as N ; it ought to be $10N$ in order that the values for MI may all be less than unity.) Statistical analysis showed that the differences in maturity between the short, intermediate and long length classes were highly significant and that there was a significant second-degree curve relationship between maturity and fibre-length. He concluded that the longest and the shortest fibres in a given lot of cotton were less mature than the fibres of intermediate lengths and that the cotton breeders, who select progenies with greater proportions of the longer intermediate fibres, select towards improvement in fibre-maturity. The curve which he obtained was concave towards the length-axis, which meant that the maturity increased from a low value to a maximum and then decreased to a point lower than the initial value as the length-grade increased from low to intermediate and from intermediate to high values.

To compare the results obtained for the eight P-A cottons with those of Hawkins, maturity-indices were calculated from the values given in Appendix II using the same formula as was given by Hawkins and were compiled as in Table I (*c*). The analysis of variance, given in Table II (*c*), led to the same conclusion as in the case of the other two maturity terms that the maturity index also showed an intrinsic variation with the length-grade. A second-degree curve was fitted and the regression equation obtained was :—

$$(MI) = 0\cdot8342 - 0\cdot04834\, l + 0\cdot004269\, l^2 \quad . \quad . \quad . \quad . \quad . \quad \text{(III)}$$

with standard errors of the regression coefficients :

$$\left.\begin{array}{r} -0\cdot04834 \pm 0\cdot00679 \\ \text{and } +0\cdot004269 \pm 0\cdot000516 \end{array}\right\}\text{equation III}$$

The regression coefficients were all highly significant and the further analysis of variance, in Table III (*c*), showed that the regression equation of the second-degree completely explained the variations in maturity-index with length-grade. The observed values of maturity-index as well as those calculated from equation III are given in columns 6, 7 of Table IV. The curve in this case (Fig. 3) was convex towards the length-axis. The maturity-index decreased from a high value to a minimum and then increased to a point higher than the initial value as the length-grade increased from 3/8 to 6/8 and from 6/8 to 10/8 inch. A closer study of the values given by Hawkins revealed the fact that all his samples were of a very low percentage of mature fibres, that is, they were predominantly immature, compared with the samples used herein. Hence, perhaps the curve given by Hawkins had the curvature in a direction opposite to that obtained in the present investigation.

V. Conclusions

From the study of the eight P-A cottons discussed in this paper, it can be concluded that, as the group-length increases from 3/8 to 6/8 inch, the mean percentage of mature fibres (and also maturity coefficient and maturity index) decreases, but further increase of group-length is accompanied by an increase of the mean maturity terms. This confirms the statement made by Gulati and Ahmad, that the correlation coefficient between spinning value and percentage of mature fibres is negative for short-staple cottons and positive for medium- and long-staple cottons.

VI. Summary

Eleven varieties of cotton grown in the Punjab were analysed into different length-grades with a Balls Sledge sorter and the fibres in each length-grade were tested for maturity. Statistical analysis was applied to eight varieties only, and all of them were improved P-A cottons with medium staple-lengths. Of the other three, one was the *desi* cotton, 39 Mollisoni, another was a new cross, Jubilee, and the third was P-A 4F, and all of these were much shorter in staple. The analysis showed that for the eight varieties, the three maturity terms, percentage of mature fibres (M), maturity coefficient (C), and maturity index (MI), varied with group-length (l) in a manner which was described by the three regression equations :—

$$M = 75\cdot734 - 7\cdot681\, l + 0\cdot620\, l^2$$

$$C = 0{\cdot}9061 - 0{\cdot}02661\, l + 0{\cdot}002410\, l^2$$
and $$MI = 0{\cdot}8342 - 0{\cdot}04834\, l + 0{\cdot}004269\, l^2$$
where l is in units of one-eighth of an inch.

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APPENDIX I

Fibre particulars of bulk samples

1. Fibre-length distribution (Balls sorter)

Mean group-length in eighths of an inch	Percentage										
	Punjab-*desi*		Punjab-American								
	39 Mollisoni	Jubilee	289F	289F/43	289F/K 25	4F	L S S	47F	58F	100F	104F
2	1·0	1·1	1·1	2·2	2·0	1·6	1·6	1·5	1·4	1·3	1·7
3	2·6	2·9	2·3	2·8	2·5	3·3	2·7	2·1	2·4	2·2	2·3
4	5·7	5·7	3·4	4·4	4·9	5·5	3·7	3·6	3·4	3·5	3·5
5	15·9	12·0	5·1	8·2	8·3	14·7	8·1	7·2	5·7	6·1	5·8
6	44·6	34·3	9·1	15·4	13·2	39·3	14·5	13·4	9·5	10·8	11·5
7	25·6	31·4	15·3	22·0	22·0	27·4	26·9	25·8	18·9	21·6	19·5
8	4·6	9·7	29·0	28·0	29·9	6·0	29·6	30·9	32·7	36·4	31·0
9	..	2·9	25·6	13·7	14·2	2·2	10·2	12·9	18·9	14·7	18·4
10	..	..	6·8	2·8	2·5	..	2·7	2·6	5·7	3·0	4·6
11	..	..	2·3	0·5	0·5	..	..	..	1·4	0·4	1·7
2. Fibre-length (cm.)— (a) Mean	1·89	1·97	2·43	2·22	2·23	1·92	2·21	2·25	2·36	2·31	2·35

(*b*) Mode	1·98	2·07	2·73	2·49	2·55	2·01	2·45	2·50	2·65	2·63	2·64
3. Fibre-length irregularity (per cent)	12·2	14·4	20·6	23·5	24·6	14·0	20·3	19·3	17·5	21·0	21·7
4. Fibre-weight per unit length (millionths of a gram per cm.)	3·00	2·55	1·49	1·32	1·51	1·90	1·65	1·63	1·78	1·64	1·49
5. Fibre-maturity test results (per cent)—											
(*a*) Mature	83·3	77·3	70·8	45·0	43·6	47·7	56·8	56·2	68·5	60·2	54·5
(*b*) Half-mature	16·3	21·0	25·8	38·7	37·2	39·2	33·5	34·5	27·0	30·9	29·5
(*c*) Immature	0·4	1·7	3·4	16·3	19·2	13·1	9·7	9·3	4·5	8·9	16·0

APPENDIX II

Number and percentages of fibres mature, half-mature and immature, maturity coefficient and maturity index in each group-length

Group-length	Number of fibres				Percentage of fibres			Maturity coefficient	Maturity index
	Total	Mature	Half mature	Immature	Mature	Half mature	Immature		
39 Mollisoni									
2 . . .	249	187	49	13	75·1	19·7	5·2	0·9221	0·8546
3 . . .	556	490	50	16	88·1	9·0	2·9	0·9617	0·9291
4 . . .	501	436	55	10	87·0	11·0	2·0	0·9616	0·9271
5 . . .	683	600	78	5	87·9	11·4	0·7	0·9674	0·9363
6 . . .	583	500	82	1	85·8	14·0	0·2	0·9639	0·9281
7 . . .	566	500	57	9	88·3	10·1	1·6	0·9661	0·9353
8 . . .	522	440	79	3	84·3	15·1	0·6	0·9590	0·9192
Jubilee									
2 . . .	337	240	62	35	71·2	18·4	10·4	0·8969	0·8145
3 . . .	511	358	124	29	70·0	24·3	5·7	0·9081	0·8276
4 . . .	530	375	109	46	71·7	20·6	8·7	0·9008	0·8191
5 . . .	526	392	100	34	74·6	19·0	6·4	0·9169	0·8468
6 . . .	510	402	88	20	78·9	17·2	3·9	0·9353	0·8784
7 . . .	534	441	74	19	82·7	13·8	3·5	0·9458	0·8987
8 . . .	502	418	75	9	83·3	14·9	1·8	0·9528	0·9092
9 . . .	504	427	71	6	84·8	14·0	1·2	0·9582	0·9188
P-A 289F									
2 . . .	502	386	91	25	76·9	18·1	5·0	0·9273	0·8645
3 . . .	555	419	86	50	75·5	15·5	9·0	0·9117	0·8414
4 . . .	532	399	108	25	75·0	20·3	4·7	0·9234	0·8562
5 . . .	512	322	146	44	62·9	28·5	8·6	0·8814	0·7801
6 . . .	544	365	136	43	67·1	25·0	7·9	0·8940	0·8039
7 . . .	548	391	113	44	71·4	20·6	8·0	0·9043	0·8246
8 . . .	540	376	137	27	69·6	25·4	5·0	0·9091	0·8281
9 . . .	573	386	157	30	67·4	27·4	5·2	0·9027	0·8159
10 . . .	523	370	141	12	70·7	27·0	2·3	0·9200	0·8445
11 . . .	511	362	131	18	70·9	25·6	3·5	0·9165	0·8401
P-A 289F/43									
2 . . .	298	135	93	70	45·3	31·2	23·5	0·7928	0·6326
3 . . .	545	271	178	96	49·7	32·7	17·6	0·8215	0·6782
4 . . .	544	210	197	137	38·6	36·2	25·2	0·7709	0·5923
5 . . .	547	233	192	122	42·6	35·1	22·3	0·7896	0·6238
6 . . .	517	202	185	130	39·1	35·8	25·1	0·7722	0·5948
7 . . .	547	195	232	120	35·7	42·4	21·9	0·7733	0·5905
8 . . .	540	235	209	96	43·5	38·7	17·8	0·8055	0·6465
9 . . .	514	243	190	81	47·3	37·0	15·7	0·8209	0·6733
10 . . .	540	259	233	48	48·0	43·1	8·9	0·8432	0·7043
11 . . .	259	136	91	32	52·5	35·1	12·4	0·8442	0·7131

APPENDIX II—*contd.*

Group-length	Number of fibres				Percentage of fibres			Maturity coefficient	Maturity index
	Total	Mature	Half mature	Immature	Mature	Half mature	Immature		
P-A 289F/K 25									
2 . . .	455	215	145	95	47·2	31·9	20·9	0·8055	0·6527
3 . . .	549	215	162	172	39·2	29·5	31·3	0·7539	0·5705
4 . . .	548	217	213	118	39·6	38·9	21·5	0·7844	0·6119
5 . . .	515	206	144	165	40·0	28·0	32·0	0·7539	0·5718
6 . . .	564	201	218	145	35·6	38·7	25·7	0·7620	0·5753
7 . . .	505	157	225	123	31·1	44·6	24·3	0·7546	0·5580
8 . . .	550	197	255	98	35·8	46·4	17·8	0·7861	0·6078
9 . . .	536	256	205	75	47·8	38·2	14·0	0·8088	0·6828
10 . . .	562	257	226	79	45·7	40·2	14·1	0·8221	0·6724
11 . . .	536	223	236	77	41·6	44·0	14·4	0·8109	0·6506
P-A 4F									
2 . . .	374	215	101	58	57·5	27·0	15·5	0·8472	0·7254
3 . . .	568	312	155	101	54·9	27·3	17·8	0·8340	0·7035
4 . . .	510	232	184	94	45·5	36·1	18·4	0·8084	0·6537
5 . . .	533	267	162	104	50·1	30·4	19·5	0·8167	0·6724
6 . . .	555	205	214	136	36·9	38·6	24·5	0·7688	0·5867
7 . . .	534	249	195	90	46·6	36·5	16·9	0·8160	0·6657
8 . . .	547	259	212	76	47·3	38·8	13·9	0·8267	0·6812
9 . . .	519	217	233	69	41·8	44·9	13·3	0·8146	0·6559
LSS									
2 . . .	385	241	92	52	62·6	23·9	13·5	0·8660	0·7590
3 . . .	501	313	122	66	62·5	24·3	13·2	0·8667	0·7597
4 . . .	548	338	136	74	61·7	24·8	13·5	0·8637	0·7544
5 . . .	530	307	140	83	57·9	26·4	15·7	0·8478	0·7270
6 . . .	534	289	171	74	54·1	32·0	13·9	0·8437	0·7152
7 . . .	530	272	188	70	51·3	35·5	13·2	0·8387	0·7038
8 . . .	554	296	181	77	53·4	32·7	13·9	0·8419	0·7116
9 . . .	506	265	203	38	52·4	40·1	7·5	0·8584	0·7377
10 . . .	523	362	124	37	69·2	23·7	7·1	0·9018	0·8178
P-A 47F									
2 . . .	459	264	127	68	57·5	27·7	14·8	0·8493	0·7283
3 . . .	541	327	145	69	60·4	26·8	12·8	0·8628	0·7512
4 . . .	588	321	194	73	54·6	33·0	12·4	0·8492	0·7233
5 . . .	524	266	189	69	50·7	36·1	13·2	0·8374	0·7011
6 . . .	524	317	136	71	60·5	25·9	13·6	0·8606	0·7483
7 . . .	574	323	185	66	56·3	32·2	11·5	0·8562	0·7354
8 . . .	559	269	225	65	48·1	40·3	11·6	0·8354	0·6941
9 . . .	544	259	215	70	47·6	39·5	12·9	0·8304	0·6866
10 . . .	554	328	186	40	59·2	33·6	7·2	0·8763	0·7671

APPENDIX II—*contd.*

Group-length	Number of fibres				Percentage of fibres			Maturity coefficient	Maturity index
	Total	Mature	Half mature	Immature	Mature	Half mature	Immature		
P-A 58F									
2 . . .	418	289	94	35	69·1	22·5	8·4	0·8977	0·8122
3 . . .	530	373	105	52	70·4	19·8	9·8	0·8965	0·8126
4 . . .	500	325	123	52	65·0	24·6	10·4	0·8813	0·7834
5 . . .	528	329	163	36	62·3	30·9	6·8	0·8853	0·7843
6 . . .	556	376	149	31	67·6	26·8	5·6	0·9023	0·8158
7 . . .	526	349	158	19	66·4	30·0	3·6	0·9050	0·8173
8 . . .	548	402	125	21	73·4	22·8	3·8	0·9219	0·8515
9 . . .	522	407	97	18	78·0	18·6	3·4	0·9346	0·8760
10 . . .	505	400	92	13	79·2	18·2	2·6	0·9403	0·8857
11 . . .	501	374	110	17	74·6	22·0	3·4	0·9264	0·8597
P-A 100F									
2 . . .	425	285	83	57	67·1	19·5	13·4	0·8774	0·7816
3 . . .	558	343	145	70	61·5	26·0	12·5	0·8660	0·7572
4 . . .	539	311	164	64	57·7	30·4	11·9	0·8586	0·7410
5 . . .	544	264	177	103	48·5	32·6	18·9	0·8145	0·6669
6 . . .	546	321	153	72	58·8	28·0	13·2	0·8574	0·7412
7 . . .	582	333	186	63	57·2	32·0	10·8	0·8606	0·7428
8 . . .	511	278	192	41	54·4	37·6	8·0	0·8619	0·7399
9 . . .	564	325	202	37	57·6	35·8	6·6	0·8744	0·7619
10 . . .	541	346	165	30	64·0	30·5	5·5	0·8932	0·7976
11 . . .	433	272	137	24	62·8	31·6	5·6	0·8904	0·7919
P-A 104F									
2 . . .	389	182	114	93	46·8	29·3	23·9	0·7952	0·6383
3 . . .	548	259	158	131	47·3	28·8	23·9	0·7964	0·6407
4 . . .	532	218	171	143	41·0	32·1	26·9	0·7718	0·5974
5 . . .	508	262	134	112	51·6	26·4	22·0	0·8128	0·6697
6 . . .	503	253	151	99	50·3	30·0	19·7	0·8167	0·6728
7 . . .	522	238	181	103	45·6	34·7	19·7	0·8048	0·6490
8 . . .	559	295	178	86	52·8	31·8	15·4	0·8358	0·7023
9 . . .	504	241	203	60	47·8	40·3	11·9	0·8338	0·6915
10 . . .	544	345	165	34	63·4	30·3	6·3	0·8898	0·7921
11 . . .	344	195	116	33	56·7	33·7	9·6	0·8629	0·7451

STUDIES IN THE PHYSIOLOGY OF RICE

I. EFFECT OF PHOSPHORUS DEFICIENCY ON GROWTH AND NITROGEN METABOLISM IN RICE LEAVES

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(With Plate XII)

THE cultivation of rice in unmanured fields and in silts deposited by various rivers is in practice throughout Bengal and other rice-growing provinces in India. The necessary elements are presumed to be present in the soil. In the case of nitrogen, De [1939] has demonstrated its fixation from the atmosphere by blue-green algae in rice fields, but in the case of phosphorus and of other elements it is not known how much is needed by the plant and how the losses occasioned by the cultivation of rice in successive years affect the metabolic activities on which the yield depends. Large tracts of soil in Bengal are known to be lacking in phosphorus and the concentration of the element fluctuates considerably in silt deposits. The crop yield varies greatly in different localities. How far the variation in yield is due to the deficiency of any particular nutrient needs to be investigated.

Owing to the importance of the problem the present investigation was undertaken to study the effect of phosphorus deficiency on growth and nitrogen metabolism of rice. The problem is a large one and requires the cultivation of rice under a wide manurial scheme. The experimental approach to the problem is twofold : (1) the plants are grown in sand culture using three levels of phosphorus and the growth data and the nitrogen metabolism of successive leaves are studied, (2) plants are subjected to an initial period of phosphorus starvation followed by the addition of the deficient element ; the subsequent changes induced in the growth rate are investigated.

Various workers have presented data having a bearing on the aspects of phosphorus nutrition considered here. An intimate relation between protein synthesis and phosphorus supply has been established by Eckerson [1931], MacGillivray [1927], Kraybill and Smith [1924] and Richards and Templeman [1936]. Richards and Templeman have made a detailed investigation on the effect of phosphorus starvation in barley, and have shown that main visual characteristics are dark green leaves and reduced number of tillers. Under phosphorus starvation nitrogen metabolism is seriously impaired, the synthesis

of protein is inhibited and there results an accumulation of amide. The feeding of detached leaves from phosphorus-starved barley with a suitable dose of phosphorus has been found by Sircar [1936] to assist protein synthesis.

Experimental procedure

A pure strain of rice, variety Bhasamanik, was used in this investigation. The plants were grown in sand culture in the open air at the experimental garden of the Botany Department of Calcutta University. Seeds* were selected for uniformity of size and colour by eye. After sterilization with 0·2 per cent formalin, nine seeds were sown in each pot in sand culture. Glazed pots 10 in. by 10 in. were used holding 30 lb. of sand, which was thoroughly washed with tap water. Each pot was provided with a hole for the drainage of surplus water. A bent glass tube fitted into the hole served also to indicate the level of water inside the pot. Water and nutrients were supplied through a small earthenware pot, placed at the centre of the culture pot.

The amounts of different nutrients required for growing rice in sand culture are unknown and an investigation is in progress in the Botanical Laboratory, Calcutta University, to determine the optimum requirements of potassium, nitrogen and phosphorus under these conditions. Pending the results of this experiment the nutrient employed is based on that of Gregory and Richards [1929] for the cultivation of barley. The same solution has yielded good results with wheat in this laboratory [Sircar, 1939]. Dastur and Malkani [1933] have suggested that both ammonium and nitrate ions are essential for rice. They found that the cation is preferentially absorbed in the early stage of development and the anion later at the time of flowering. In view of this in the present experiment ammonium nitrate replaced the sodium nitrate of Gregory's solution.

The following weights of salts per pot were used as the standard nutrient :—

Ammonium nitrate (NH_4NO_3)	3·00 gm.
Sodium hydrogen phosphate ($Na_2HPO_4 . 12 H_2O$)	2·52 ,,
Magnesium sulphate ($MgSO_4 . 7H_2O$)	1·27 ,,
Potassium sulphate (K_2SO_4)	1·85 ,,
Calcium chloride ($CaCl_2 . 6H_2O$)	0·37 ,,

Traces of ferric chloride and manganese sulphate.—For phosphorus deficiency two levels of phosphorus were used, namely 1/3rd and 1/27th of the standard amount, each pot thus receiving 0·84 gm. and 0·093 gm. of phosphate respectively. The three series are designated full manure (1·00 P), 0·33 phosphorus (0·33 P) and 0·037 phosphorus (0·037 P). In treatments full manure and 0·33 P, 20 pots each and in 0·037 P, 26 pots were used.

In the deficient series the reduction in sodium necessitated by the reduction in phosphorus was corrected by the addition of the requisite amount of sodium sulphate. After 12 weeks the deficiency in six pots of 0·037 P series was made good by the addition of 2·427 gm. of sodium hydrogen phosphate per pot.

* Seeds of variety Bhasamanik were obtained from the Chinsurah Rice Research Station of the Department of Agriculture, Bengal, for which thanks are due to the authorities.

Growth of rice seedlings with different nutrients

Germination of the seeds was complete in the course of a week. When the seedlings were a little developed and the first leaf unfolded, the plants were thinned to three per pot uniform in size and spacing. The nutrients were applied to the young plants in dilute solutions in three weekly doses. In each dose salts were dissolved separately in 25 c.c. distilled water and then the *p*H of the solution was adjusted to 6·5. The first dose was applied immediately after the plants were thinned down and the last dose on 14 August 1938 after the emergence of the sixth leaf.

During the first month tap water was used for watering: the rains then set in. The excess of rain water was drained through the hole at the bottom of the pot and was collected in a bottle, whence it was subsequently returned to the pot, thus avoiding any loss of nutrients. Owing to the heavy shower of rains in the monsoon months, the probability of overflow of water from the pot with a consequent loss of nutrients was high. This was prevented by placing a tin cover over the pot. The tin cover is made in three sections and is easily detachable when necessary. It is provided with three holes to allow the plants to grow freely (Plate XII). With this arrangement it is possible to prevent any overflow during heavy showers.

Analytical method

In each pot there were three plants, so besides growth measurement there were sufficient plants for leaf sampling. Eight to ten leaves, just at the time of their complete maturity, were collected at random from the main shoot of different pots before 8 A.M. and were taken to the laboratory in glass tubes lined with moistened filter paper. With the treatments adopted, the times taken to reach complete maturity by corresponding leaves differed by only a few days.

The leaves were immediately bisected longitudinally, cut into small bits and weighed. One half was dried at 70°C. for 24 hours and finally at 100°C. for 30 minutes. The dried leaves were powdered in a mortar and from the dry powder total nitrogen was estimated using the micro-Kjeldahl apparatus of Parnas and Wagner as described by Pregl [1930]. Reduction of nitrate was carried out by the reduced iron method of Pucher, Leavenworth and Vickery [1930]. Meanwhile the other half was thoroughly ground in a mortar to a paste with phenol-water. The extract was filtered through paper pulp and made up to 50 c. c. with several washings of distilled water by using a filter pump. Frothing was prevented by adding a few drops of capryl alcohol. It was found that after adequate grinding with strict economy in the use of washing water about 97-98 per cent of the soluble nitrogen could be extracted in this volume of water. Protein was removed from the extract by adding 50 per cent solution of trichloracetic acid in the proportion of 1 c. c. acid to 19 c. c. extract and filtering. From the filtrate total crystalloid nitrogen was estimated as before by the micro-Kjeldahl method after reduction of nitrates. Protein nitrogen was calculated by the difference between the total nitrogen and crystalloid nitrogen content.

Total amino nitrogen was determined by an adaptation of Brown's modification [1923] of Sorensen's formol-titration method. Amide nitrogen was estimated by hydrolysing the protein-free extract with sulphuric acid and estimating the ammonia produced by Wolff's method [1928].

Experimental results

Growth analysis

Weekly tiller count and height measurements of the plants were taken from the seventh week after sowing. The measurement adopted was the length of the main shoot from its base to the tip of the highest leaf. Since 20 plants would suffice for statistical analysis, one particular plant from each pot was measured in successive weeks. The mean values of height and tiller number of 20 plants per week are given in Tables I and II respectively. During the first five weeks all the plants were indistinguishable, differences first becoming noticeable during the sixth week. From the seventh week onward, a very marked difference in the general appearance of the plants grown under different levels of phosphorus was noticed.

Table I

Height in cm.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full manure (1·00 P)	44·32	50·92	58·10	62·25	67·99	70·37	74·07	79·51
0·33 P . .	45·37	50·03	54·85	61·42	65·42	68·64	71·66	77·38
0·037 P . .	39·85	46·10	49·19	53·28	59·40	62·04	64·89	71·05
0·037 P + 0·963 P	..	..	..	..	..	..	73·53	82·45

Table II

Tiller No.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full manure (1·00 P)	2·20	2·65	3·90	4·75	5·50	6·05	7·25	7·85
0·33 P . .	2·05	2·35	2·85	3·05	3·20	3·25	3·75	4·00
0·037 P . .	1·10	1·55	2·10	2·25	2·65	2·65	2·75	2·85
0·037 P + 0·963 P	..	..	..	..	..	..	3·16	4·00

The plants from the full-manure series were the most vigorous in vegetative growth and became bushy (Plate XII), but none of them produced ears. In deficient series on the other hand with fewer tillers and reduced vegetative growth the plants produced fertile ears. The failure of the high phosphorus plants to flower in conjunction with their excessive vegetative growth is possibly due to a very high uptake of nitrogen leading to low carbon-nitrogen ratio.

Starvation symptoms included dull green to yellowish green leaves, and this colour difference is more pronounced in 0·037 P series than 0·33 P series. The leaves were reduced in size and after full emergence their distal ends were dried up. In the six pots of 0·037 P series, to which phosphorus was added during the 12th week, the rate of growth increased and symptoms of starvation disappeared. With the renewal of growth, the height of the plant and the tiller number increased considerably (Plate XII).

In the 0·037P series the size of the ear was very much reduced, but the late addition of phosphorus to the phosphorus-starved plants greatly improved the grains.

Statistical analysis of growth data

In order to judge the significance of treatment the data were subjected to statistical examination by the technique of the analysis of variance. The ratios of the variance between treatments (2 degrees of freedom) to that 'within' treatments (57 degrees of freedom) for the later sampling times are given in Table III with their respective expected values at the 5 per cent and 1 per cent levels.

Table III

Analysis of variance

Weeks after sowing	Observed ratio of variance		Expected ratio of variance	
	Height	Tiller	1 per cent	5 per cent
VII	7·03	20·20	4·98	3·15
VIII	4·60	8·54	4·98	3·15
IX	10·55	12·96	4·98	3·15
X	11·03	20·60	4·98	3·15
XI	6·04	31·10	4·98	3·15
XII	19·30	36·70	4·98	3·15
XIII	5·01	56·40	4·98	3·15
XV	5·51	88·70	4·98	3·15

All the observed ratios are significant at 1 per cent level except that for height in the eighth week and this nearly reaches the same level. The mean differences in the case of tiller number (Table V) increase regularly with age, signifying that the effect of treatments becomes more and more pronounced with age.

The superiority of full manure to 0·33 P and 0·037 P and that of 0·33 P to 0·037 P as judged from their effect on height and tiller number are shown by the difference of the means given in Tables IV and V respectively.

Significances at 5 per cent and 1 per cent levels of probability have been marked with (*) and (**) respectively.

TABLE IV

Height in cm.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full manure—0·33 P	−1·05	+0·89	+3·25	+0·83	+2·57	+1·73	+2·41	+2·13
Full manure — 0·037 P	** +4·47	** +4·83	** +8·91	** +8·97	** +8·59	** +8·33	** +9·18	** +8·46
0·33 P —0·037 P	** +5·52	* +3·93	** +5·66	** +8·14	** +6·02	** +6·60	* +6·77	** +6·33

TABLE V

Tiller No.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full Manure — 0·33 P	+0·15	+0·30	** +1·05	** +1·70	** +2·30	** +2·80	** +3·50	** +3·85
Full Manure — 0·037 P	** +1·10	** +1·10	** +1·90	** +2·50	** +2·95	** +3·40	** +4·50	** +5·00
0·33 P —0·037 P	** +0·95	** +0·80	* +0·85	* +0·80	+0·55	+0·60	* +1·00	** +1·15

The effect of the addition of 0·963 phosphorus to the 0·037 P series as measured by height and tiller number is given in Tables I and II respectively. The significance of the effect in both the groups was examined as before. The ratios of variance between treatments (one degree of freedom) and within treatments (24 degrees of freedom) are given in Table VI with the expected variance ratios at 5 per cent and 1 per cent levels.

TABLE VI

Ratios of variance

Weeks after sowing	Observed ratio of variance		Expected ratio of variance	
	Height	Tiller	5 per cent	1 per cent
XIII	1·9	1·09	4·26	7·82
XV	8·2	13·6	4·26	7·82

The effect of treatment is not significant at the 13th week but is highly significant at the 15th, i.e. the application of phosphorus even at this late stage of life induces tillering and increases height.

Nitrogen analysis

The results of nitrogen fractionations are presented in Table VII as percentage of dry weight.

For lack of replicate observations these results are presented without statistical evidence. Since the analytical data as reported here are obtained from a representative number of leaves of the same stage of maturity, it is worth considering the appreciable difference between treatments. In amino acid, amide and residual nitrogen there are minor fluctuations, but from the general trend of behaviour in different leaf number the effect of phosphorus concentration is noteworthy.

Total nitrogen

In all the leaves in the full-manure series total nitrogen content is high and the level falls with decreasing phosphorus concentration. After the eighth leaf the total nitrogen falls in the successive leaves and this fall with leaf number is evident at all levels of phosphorus. The eighth leaf in all the series absorbed more nitrogen. The uptake of nitrogen then is dependent on the supply of phosphorus. Higher levels of phosphorus result in increased absorption of nitrogen. This is clearly seen in the three levels of phosphorus used in the experiment. Richards [1938] found that with increasing supply of phosphorus in the early stages of growth the uptake of nitrogen is increased.

Protein nitrogen

The highest content of protein nitrogen is found in the full-manure series and the content falls progressively with decreasing concentration of phosphorus.

TABLE VII

Nitrogen fractions expressed in percentage of dry weight

Leaf No.	Treatment	Total N	Crystal-l oid N	Protein N	Total amino N	Amide N	Amino acid N	Residual N
7	F. M.*	4·287	1·286	3·001	0·0461	0·0228	0·0233	1·2170
	0·33 P	3·929	1·274	2·655	0·0567	0·0425	0·0142	1·1747
	0·037 P	3·675	0·9931	2·6819	0·0342	0·0301	0·0041	0·9288
8	F. M.	4·382	0·6336	3·7484	0·1848	0·0293	0·1545	0·4195
	0·33 P	3·965	0·6181	3·3469	0·1429	0·0598	0·0832	0·4155
	0·037 P	3·796	0·6141	3·1819	0·1848	0·1121	0·0727	0·3172
9	F. M.	4·1875	0·4494	3·7381	0·1266	0·0344	0·0923	0·3084
	0·33 P	3·6846	0·5316	3·1530	0·1557	0·0944	0·0613	0·2815
	0·037 P	3·2865	0·4173	2·8692	0·1833	0·1153	0·0680	0·1187
10	F. M.	3·5645	0·3636	3·2009	0·0867	0·0286	0·0581	0·2482
	0·33 P	3·2493	0·3383	2·9110	0·0915	0·0394	0·0521	0·2175
	0·037 P	2·9005	0·3874	2·5131	0·1003	0·0733	0·0270	0·2138

* F. M.=Full manure

These relations are found in each of the four leaves investigated. The effect of phosphorus starvation in lowering the protein content is more marked in the later leaves, the 9th and 10th leaves, showing greater variation in protein content between treatments than the 7th and 8th. The decrease in protein nitrogen with falling phosphorus supply closely simulates that of total nitrogen. It will be noted that as compared with total nitrogen, protein nitrogen content rises more steeply from leaf 7 to leaf 8 and that the subsequent decline is rather slower. As between the 7th and 8th leaves therefore there is a consistent difference, at all phosphorus levels, of the relative contents of protein and crystalloid nitrogen.

Amino acid nitrogen

In estimating the values for amino acid nitrogen the following assumption is made. It is generally believed that the plant amide exists mainly in the form of asparagine which behaves as a mono-carboxylic mono-amino acid. Since one of the COOH group of aspartic acid is neutralized by the amide group, only one is available for formol-titration. The formol-titration figures therefore included only half of the total nitrogen of asparagine. The amide figures also include half the nitrogen of the asparagine. Hence the absolute values of 'amino acid nitrogen' presented here (all amino acids less those united to an amide group) are estimated from the difference between the formol-titration figure and the amide titration figure.

The amino acid values in all treatments increase from the 7th leaf to the 8th and subsequently fall again, but a value higher than that of the 7th leaf is maintained up to the 10th. Somewhat similar relationships were found with protein nitrogen content. Increasing phosphorus starvation has resulted in a progressively reduced amino acid content, and this is found in all the leaves. The results presented here do not seem to agree with those obtained by Richards and Templeman [1936], who noticed in barley a higher amino acid content in phosphorus-starved than in full-manure leaves.

Amide nitrogen

No separate estimation of ammonia was made, hence the amide figures presented here will include in addition all the free ammonia that may be present in the leaves. As the plants were supplied with ammonium nitrate, this may be absorbed in considerable amounts, but Prianischnikoff [Onslow, 1931] has shown that free ammonia, which is toxic, is quickly converted to asparagine. From this it may be presumed that the ammonium ion if present at all is in inappreciable quantity.

Amide nitrogen from the 7th leaf increases to the 9th, but in the 10th it again falls. A large and progressive increase in amide nitrogen following the lowering of phosphorus concentration is found in the leaves analysed. Strikingly high amide contents are found in the 8th and 9th leaves of the most deficient series ; the content falls again in the 10th leaf but still remains higher than in the 7th. The results are in agreement with those of Richards and Templeman, who noticed an accumulation of amide in barley grown under phosphorus deficiency. As the plants age, the accumulation of amide under phosphorus deficiency is presumably a reflection of the retarded rate of protein synthesis.

Residual nitrogen

The residual crystalloid nitrogen is the nitrogen not estimated in any of the other groups. The figures are obtained from the difference between the total crystalloid nitrogen and the sum of total amino and amide nitrogen. Since the plants were supplied with ammonium nitrate, the residual crystalloid nitrogen will contain any nitrate remaining unmetabolized. No separate estimation of nitrate was made, but possibly the nitrate content may be roughly estimated from the residual crystalloid nitrogen content.

In the 7th leaf a high value of residual nitrogen is observed and this falls rapidly in later leaves, a very sharp fall occurring from the 7th to the 8th. If it be assumed that residual nitrogen consists largely of nitrate, then it follows that up to the 7th leaf much of the absorbed nitrate has remained unmetabolized. The contents of amide nitrogen in the 7th leaf are low, and these include also all free ammonium ion. Hence ammonia is either not absorbed in these earlier stages or else is metabolized to protein as soon as it is absorbed. But Dastur and Malkani [1933] have definitely shown that the ammonium ion is absorbed in larger quantities than is nitrate in the earlier stages. Hence it appears likely that ammonia is utilized for the synthesis of protein as soon as absorbed, while the absorbed nitrate remains largely unused and accumulates at this time. In the 8th leaf a large reduction in residual nitrogen is noticed, and this accompanies a roughly equal increase in protein nitrogen. Reduction in phosphorus concentration lowers the residual nitrogen content just as it does the total nitrogen content and that of all observed fractions with the exception of amide.

Nitrogen analysis of the ears

Since only 6 pots were used for the application of phosphorus to phosphorus-starved plants, the leaf material was insufficient for estimating the various nitrogen fractions in the successive leaves. But from the ripe ears nitrogen analyses were made and the data are presented in Table VIII.

TABLE VIII

Analysis of ears

Treatment	Total N	Crystalloid N	Protein N	Total amino N	Amide N
0·33 P	1·9313	0·1362	1·7951	0·0079	Trace
0·037 P	1·6970	0·1678	1·5292	0·0158	,,
0·037 P + 0·963 P . .	1·9393	0·1496	1·7897	0·0085	,,

It is evident that nitrogen content in the ears has increased after the addition of phosphorus. The increase in total nitrogen is accompanied by an increase in protein nitrogen, while only traces of amide and amino nitrogen are found ; nearly all the soluble nitrogen appears as 'residual nitrogen'. The probability of the presence of nitrate in the grains in concentrations, such

as those of residual nitrogen, is very unlikely, and further research is necessary to determine the nature of the substances represented. They may consist largely of relatively short-chain compounds intermediate between amino acids and protein.

Discussion

The differences in phosphorus supply have produced marked changes in the growth of rice plants, and the characteristic symptoms of phosphorus deficiency noted by Richards and Templeman [1936] in the leaves of barley are observed also in these leaves. At the highest level of phosphorus vigorous vegetative growth occurs, and as the phosphorus level is reduced a marked decrease in both tillering rate and height of the plant results. These are found to be statistically significant. At the intermediate phosphorus level the height effect, which appears to be real enough, cannot be shown to be statistically significant, since the observations in successive weeks are not independent, so that the data for each week must be considered individually instead of collectively. The effect on tillering is shown to be highly significant from the 9th week onwards and increases with time. At the lowest phosphorus level significant reductions in both height and tiller numbers are found even at the earliest observations and these become more pronounced with increasing age. It should be noted that the plants, which have suffered this severe deficiency for 12 weeks and are then supplied with phosphorus, recover immediately, beneficial effects being noticeable one week after the change in conditions. The deficiency symptoms disappear, tillering is renewed and growth in height accelerated. On the other hand, Brenchley [1929], working with barley, found phosphorus to be necessary in the early stages of growth, later application being unaccompanied by the formation of new tillers. The critical period was found to be between four and six weeks after sowing, later application of phosphorus to starved plants having no appreciable effect in increasing tiller number. The considerable difference in behaviour between barley used by Brenchley and rice used in the present experiment may possibly be explained by the difference in the normal rate of tillering of the two species. In barley Brenchley found a rapid rate of tiller formation in the first four weeks after which the rate began to slacken off. The majority of new tillers formed during the later period remained small and died prematurely. In rice the maximal rate of tillering is later and the period over which new shoots are produced is prolonged. Tiller production at any one stage of life-history is not only a function of the nutrient supply at that time, but is also a function of certain internal factors—differing in different species—responsible for the shape of the tiller productions curve under constant external conditions.

This investigation clearly shows that the absorption of nitrogen is dependent on the supply of phosphorus. As the external concentration of phosphorus is varied over a wide range, the uptake of nitrogen varies in the same sense. These results are in accord with those of Richards and Templeman for barley, but do not agree with those recorded by MacGillivray [1927] for tomatoes. He found that plants growing in sand culture under phosphorus deficiency have a higher percentage of nitrogen than those grown with ample supplies of phosphorus.

When leaves from the plants of the present experiment are compared with those from rice grown in the field,* it is found that the nitrogen content in sand culture is considerably higher than that from the soil plants. Rice plants evidently can grow normally at lower nitrogen levels than that of this experiment. In the full-manure series the excess nitrogen absorption may be the main cause of the plants making excessive vegetative growth and failing to form ears. With low phosphorus supply the uptake of nitrogen is reduced and the resulting plants produce ears ; in this respect 0·037 P plants were the best. Almost all the plants in this series formed grains, in 0·33 P series about 40 per cent produced them, while in full manure series none of the plants produced them. In 0·037 P series the total nitrogen of the 10th leaf—the last one analysed—was 2·9 per cent, a value but slightly above that obtained in the corresponding leaf of the plants grown in the field, where both good vegetative growth and good grain was noticed (2·5 per cent).

Protein nitrogen is affected by phosphorus supply in the same way as total nitrogen, the lowering of phosphorus concentration resulting in a lowering of protein nitrogen content. The decrease in protein nitrogen under phosphorus starvation is accompanied by an accumulation of amide, this accumulation being greatest under conditions of greatest deficiency. Under the same conditions the content of amino nitrogen, other than that associated with an amide group, is reduced. The accumulation of amide under phosphorus starvation has been noticed by Richards and Templeman in barley leaves, and they suggested that under these conditions protein synthesis is checked beyond the stage of the production of asparagine. Unpublished work by Sircar [1936] has shown that when phosphorus and sugar are presented in the dark to detached leaves of barley deficient in phosphorus, an increase in protein results. It was concluded that phosphorus is necessary for the synthesis of amide to protein.

In the rice leaves it has been observed that starvation symptoms disappear when deficiency is made good, and there is renewed growth in the plants as is evident from the increase in height and tiller number. This result presumably follows the revival of protein synthesis in these plants. Nitrogen analyses of the grain show increased contents of nitrogen following phosphorus feeding, and a considerable portion of the increased nitrogen is metabolized to protein (Table VIII). Evidently phosphorus is necessary for the utilization of nitrogen, but from the evidence presented here and elsewhere [Richards and Templeman 1936; Sircar, 1936] it is impossible to decide whether the main effect is direct or indirect.

Summary

1. A sand-culture experiment is described in which rice var. Bhasamanik was grown at three levels of phosphorus nutrition : (1) Maximal phosphorus—the full-manure series, (2) 0·33 phosphorus at one-third the level of phosphorus used in full-manure series, and (3) 0·037 phosphorus at 1/27th.

* An investigation on the nitrogen metabolism of the successive leaves of rice plants grown in the field is in progress, and the total nitrogen estimated in leaves No. 7, 8, 9, 10 is found to be 2·66, 2·85, 2·53, 2·51 respectively.

2. Maximum height of the plants and number of tillers were observed periodically. Progressive phosphorus deficiency leads to progressive reduction in height and tillering. The application of phosphorus to 0·037 P plants 12 weeks after sowing increases tiller number and height. The growth data are analysed statistically, and the effects of phosphorus are found to be highly significant.

The uptake of nitrogen is found to depend on phosphorus concentration, greatest uptake being associated with the highest phosphorus level. Protein synthesis is checked by shortage of phosphorus supply, and an accumulation of amides results. Free amino-acid content is reduced by phosphorus deficiency.

The effect of retarded phosphorus application is also seen in increased total nitrogen content and protein synthesis in the grains. These results demonstrate that in rice, phosphorus is not only useful in the early stages of growth but may also be utilized in the later stages of development.

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STUDIES ON INDIAN RED SOILS

II. FIXATION OF PHOSPHATES

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(With one text-figure)

HECK [1934] has made the following divisions of the inorganic compounds of phosphorus present in the soil :—

(*i*) Readily available fixed phosphorus—$Ca_3(PO_4)_2$

(*ii*) Moderately available fixed phosphorus—$AlPO_4$

(*iii*) Difficultly available fixed phosphorus—$FePO_4$, $Fe_2(OH)_3PO_4$, $Al_2(OH)_3PO_4$

The basis of this division is the solubility of these compounds in $0 \cdot 002N$ sulphuric acid solution buffered to *p*H $3 \cdot 0$ by adding 3 gm. of ammonium sulphate per litre.

Ford [1933] showed that fixation of phosphates by iron in difficultly soluble form is due to the hydrated iron oxides, such as goethite, which forms very difficultly soluble iron phosphates. The work of Gaarder [Heck, 1934] indicates that the *p*H value of the soil is an important factor in influencing the form in which phosphate is fixed up by the soil. His work shows that the amount of phosphorus going into solution from calcium phosphate at *p*H $6 \cdot 5$ is only about one-third of that from normal aluminium phosphate and one-fourth of that from normal iron phosphate, whereas at *p*H $5 \cdot 5$ the phosphorus from normal calcium phosphate has a solubility from three to five times of that in iron and aluminium forms. Besides iron and aluminium, the inorganic elements Mg, Mn and Ti may also function to some extent in the fixation of phosphorus in the soil, but their importance and exact role is either unknown or is questionable. Indeed, Bradfield, Scarseth and Steele [1935] say : 'Natural soils contain so many substances capable of fixing phosphates that it is hopeless to unravel the mechanism of fixation by the study of such complex systems '. The work of these authors shows that at *p*H values $2 \cdot 0$-$5 \cdot 0$, the retention of phosphates is chiefly due to the gradual dissolution of iron and aluminium and their reprecipitation as phosphates. At *p*H values $6 \cdot 0$-$10 \cdot 0$, if divalent cations are present, the phosphate will be largely fixed by divalent cations, whereas at *p*H values $4 \cdot 5$-$7 \cdot 5$, the retention of phosphates by clays seems to be surface reactions in which OH

ions are displaced by phosphates. Thus their work suggests that the capacity of the soil to retain phosphate ions over a wide range of reactions and concentrations is due at least to three distinctly different mechanisms.

Mention may be made here of the work of Fraps [1932] who reported that various soil minerals other than iron compounds possess the capacity of fixing phosphates. Similar results were obtained by Dean [1934].

In the present investigation Truog's [1930] method for determining the amount of available phosphates has been employed.

The present work has been divided into two sections.

Section I deals with a study on the uptake of phosphates from phospate solutions by soils after shaking the mixture of the soil and the phosphate solution for a certain time.

Section II deals with a study on the fixation of phosphates by soils from phosphate solutions when the latter are brought into equilibrium with the soil by evaporation to dryness.

Data and discussion

I. Study on the uptake of phosphates from phosphate solutions by soils after shaking the soil and the phosphate solution for a certain time

Experimental

Procedure for the determination of the uptake of phosphates

0·5 gm. of powdered soil passing through a 70 I. M. M. mesh were treated with 25 c.c. of a standard phosphate solution (H_3PO_4, KH_2PO_4,K_2HPO_4,K_3PO_4 as the case may be) containing 4 p.p.m. of phosphorus per c.c. (then phosphorus content with respect to soil is 200 p.p.m.) in 30 c.c. test-tubes. The soils were shaken for a certain time in a mechanical shaker, then immediately filtered through a Whatman No. 2 filter paper, the first few c.c. being discarded. A definite quantity of the filtrate was taken and P content determined according to Truog and Meyer's modification of Denige's method [1929].

Preparation of standard phosphate solutions

KH_2PO_4 solution.—0·1755 gm. of KH_2PO_4 (extra-pure, Merck) was dissolved in water and diluted to 1,000 c.c. This solution contains 40 p.p.m. of P.

K_2HPO_4 solution.—0·2245 gm. of K_2HPO_4 (extra-pure, Merck) was dissolved in water and diluted to 1,000 c.c. This solution contains 40 p.p.m. of P.

K_3PO_4 solution.—0·2754 gm. of K_3PO_4 (extra-pure, Merck) was dissolved in 1,000 c.c. of water. This solution contains 40 p.p.m. of P.

H_3PO_4 solution.—4 c.c. of phosphoric acid was diluted to 100 c.c. and 1 c.c. of this was taken and P determined according to Truog and Meyer's modification of Denige's method. It was found to contain 1,168 p.p.m. of P, 3·42 c.c. of this was diluted to 1,000 c.c., so that P content of this solution was 4 p.p.m.

Determination of pH.—pH was determined by the colorimetric method using the Hellige Comparator.

Results

The results are presented in Tables I and II.

Table I

Amount of P taken up by the soil, when the soil is shaken with 200 p.p.m. of P (KH_2PO_4 solution used)

Locality	Soil No.	Depth	p. p.m. of P taken up by the soil after shaking for different times in minutes						
			0*	30	60	90	120	180	240
Dacca Farm (Bengal)	1p	0—6 in.	73	80	130	133	136	142	142
	2p	0—2 ft. 3 in.	129	182	183	185	187	190	195
	3p	2 ft. 3 in.—4 ft.	130	181	182	183	182	183	183
Suri, Birbhum (Bengal)	5p	1 ft.—1 ft. 6 in.	73	151	158	160	168	169	170
	8p	Below 13 ft.	26	66	112	120	123	123	123
Himayatsagar (Hyderabad)	18p	0—3 in.	87	120	123	123	128	132	133
	19p	3 in.—1 ft. 6 in.	26	115	116	136	136	136	136
	20p	1 ft. 6 in.—4 ft.	30	26	65	66	66	66	66
	21p	1 ft. 6 in.—4 ft.	62	56	74	75	75	76	76
Telankheri (1) Nagpur (C. P.)	23p	0—2 ft.	56	111	144	156	162	174	174
	24p	2 ft.—2 ft. 6 in.	83	176	177	180	183	184	184
Telankheri (2) Nagpur (C. P.)	26p	13 ft.—16 ft.	60	63	63	63	63	63	63
	27p	16 ft.—21 ft.	39	68	69	69	69	69	69
Chandkhuri Farm, Raipur (C. P.)	33p	0—4 in.	80	88	91	100	106	111	112
	34p	4 in.—1 ft. 5 in.	100	142	142	150	151	151	151
	35p	1 ft. 5 in.—4 ft.	103	180	180	180	180	180	180
Puzathi, Cannanore (Madras)	48p	16 ft.—30 ft.	83	125	125	128	132	137	139
	50p	Below 30 ft.	32	115	115	121	126	126	126
	51p	Below 30 ft.	36	50	50	50	50	50	50
Nilgiri hills (1) 3,000 ft. a.s.l.	53p	0—1 ft. 8 in.	32	115	115	115	115	115	115
	54p	1 ft. 8 in.—3 ft.	37	111	139	138	140	142	154
	55p	Below 54p	68	125	126	126	126	126	126
Nilgiri hills (2), 5,000 ft. a.s.l.	56p	0—1 ft. 2 in.	25	108	129	151	174	174	174
	57p	1 ft. 2 in.—2 ft.	182	190	195	200	200	200	200
	58p	2 ft.—6 ft.	137	191	198	200	200	200	200
Nilgiri hills (3) 7,000 ft. a.s.l.	59p	0—1 ft.	40	146	158	159	163	171	195
	60p	1 ft.—3 ft.	190	197	200	200	200	200	200
	61p	3 ft.—4 ft. 6 in.	185	192	196	200	200	200	200
	62p	4 ft. 6 in.—6 ft.	190	199	200	200	200	200	200

* This reading was actually taken after one or two minutes from the time of mixing the soil and the phosphate solution, which time was necessary for shaking the soil with solution and taking measurements.

TABLE I—*contd.*

Locality	Soil No.	Depth	p.p.m. of P taken up by the soil after shaking for different times in minutes						
			0*	30	60	90	120	180	240
Stambhalaguruva, Guntur (Madras)	67p	0—8 in.	30	96	99	121	126	138	146
	69p	1 ft. 2 in.—6 ft.	58	127	127	129	130	130	130
Limonite			75	79	93	115	117	118	120
Magnetite			53	66	66	66	66	66	61
Ilmenite			69	68	86	96	103	140	142
Kaolin (Indian)			20	22	22	22	22	22	21
Bauxite (Indian)			114	137	137	141	148	162	178

* This reading was actually taken after one or two minutes from the time of mixing the soil and solution, which time was necessary for shaking the soil and taking measurements.

TABLE II

Analytical data of minerals (air-dry basis)

Minerals	SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	TiO_2 (per cent)	P_2O_5 (per cent)
Limonite *	2·04	5·53	76·96	1·79	0
Magnetite *	1·51	1·65	94·26	0·52	0
Ilmenite *	2·03	1·26	47·19	46·97	0
Kaolin *	39·53	11·38	2·10	0·10	0
Bauxite *	0·20	96·87	1·48	1·00	0

* These are all Indian minerals.

The mineral limonite and the titanium-bearing mineral ilmenite possess almost the same power of retaining phosphates. In many cases, the soil possess much greater power of retaining phosphates than the above minerals, whilst in some cases, the powers of soils to retain phosphates are considerably less.

It will be found from Table I that in most cases, up to about 30 minutes or one hour, the phosphate fixation proceeds at a rapid rate, the rate gradually falling off, becoming almost constant after two hours and remaining thus for the remainder of the period, during which observations were made. It will be noted that the procedure developed for comparing the fixing powers of soils involved the agitation of the soil and the phosphate solution from a few minutes to a few hours. It should not be inferred, however, that fixation is complete at the end of this period. The period required for the attainment of a true equilibrium between the soil and a soluble phosphate which has been applied to it will depend upon the nature of the soil, the magnitude of application of the phosphate and the manner in which the resulting fixation is brought

about. The investigations of Davis (cited by Hance [1933]) of a high-fixing Manoa Valley soil indicate that equilibrium is not reached even after several weeks of continuous agitation of the soil-phosphate solution mixture.

The results in Table I also indicate that the adsorption of phosphates is the highest in the case of profile samples from Nilgiri hills (2) (5,000 ft. above sea level) and Nilgiri hills (3) (7,000 ft. a.s.l) and is considerably greater than in the case of the ordinary iron or titanium-bearing minerals. The most plausible explanation of this lies in the fact that there are materials present in the soil other than iron or titanium-bearing minerals, which possess considerable power of phosphate absorption. An alternative explanation can be offered that the soils of Nilgiri hills (2) and Nilgiri hills (3) are rich in colloidal iron.

Table III shows the uptake of phosphorus when phosphate is added to the soil in different forms.

The data show in general that the amount of phosphate absorbed by the soil at about equilibrium point increases with the lowering of pH of the phosphate solution. The high uptake of P in case of H_3PO_4 may partly be due to the coming into solution of iron and aluminium and their reprecipitation as iron and aluminium phosphates, whilst in case of K_3PO_4 the reaction is probably between divalent cations and the phosphate solution, and hence the uptake is comparatively small [Bradfield, Scarseth and Steele, 1935].

TABLE III

Amount of P taken up by the soil from different solutions

Soil description	Phosphate solution used *	p.p.m. of P taken up by the soil after shaking for different times (in minutes)						
		0**	30	60	90	120	180	240
2p, Dacca Farm (Bengal) (6 in.-2 ft. 3 in.)	H_3PO_4	14	67	178	200	200	200	200
	KH_2PO_4	129	182	183	185	187	190	195
	K_2HPO_4	21	104	155	155	158	158	158
	K_3PO_4	8	96	96	96	97	97	97
5p, Suri, Birbhum (Bengal) (1ft.-1 ft. 6 in.)	H_3PO_4	52	166	173	189	200	200	200
	KH_2PO_4	73	151	158	160	168	169	170
	K_2HPO_4	94	103	114	114	114	114	114
	K_3PO_4	25	61	70	81	82	83	83
23p, Telankheri, Nagpur (C. P.) (0 -2 in.)	H_3PO_4	138	164	186	200	200	200	200
	KH_2PO_4	56	111	144	156	162	174	174
	K_2HPO_4	33	102	102	102	121	121	135
	K_3PO_4	81	84	84	84	84	84	84
59p, Nilgiri hills (3) (0-1 ft.)	H_3PO_4	144	150	170	184	200	200	200
	KH_2PO_4	40	146	158	159	164	171	195
	K_2HPO_4	84	177	178	178	178	179	179
	K_3PO_4	64	63	67	70	72	75	75
67p, Stambhalaguruva, Guntur (Madras) (0-8 in.)	H_3PO_4	130	149	185	200	200	200	200
	KH_2PO_4	30	96	99	121	126	139	146
	K_2HPO_4	2	77	79	81	93	102	103
	K_3PO_4	14	14	14	15	15	15	16

* pH of the phosphate solutions are :—

H_3PO_4 3·8 ; KH_2PO_4 5·6 ; K_2HPO_4 7·2 ; K_3PO_4 9·6.

**This reading was actually taken one or two minutes from the time of mixing the soil and phosphate solution which time was necessary for shaking and taking measurements.

II. Fixation of phosphates by soils from phosphate solutions when the latter are brought into equilibrium with the soil by evaporation to dryness

Experimental

Following the work of Scarseth, Heck [1934] has found that the most pronounced fixation of phosphate occurs in a few hours and that after a transition period, varying from two to ten days, the fixation takes the form of practically a straight line with a tendency to be somewhat asymptotic, which approaches the line of ' zero ' recovery. Heck [1934] found also that heat could in part be substituted for time and this could be accomplished by refluxing the soil in the phosphate solution at 100°C. for 45 minutes. It was also found that if the soil and the phosphate solutions were slowly boiled to dryness, the results were the same as when they are refluxed. The following procedure, which was adopted, is essentially the same as developed by Heck.

Procedure for treating the soil and phosphate solution mixture

0·5 gm. of soil, which passes through a 70 I. M. M. sieve, was placed in a 600-c.c. tall Pyrex beaker and to it 250 c.c. of KH_2PO_4 solution containing 0·000001 gm. of P per c.c. was added. This was equivalent to adding 500 p.p.m. of P to the soil. The beaker was then slowly heated to dryness in a sand-bath, till the contents were dry. It usually took six to seven hours. The dried mass was then transferred to a 500-c.c. wide-mouthed bottle and treated with 250 c.c. of 0·002 N sulphuric acid solution buffered to pH 3·0 by adding ammonium sulphate [Truog and Meyer, 1930], and shaken for half an hour in a mechanical shaker. From the extract, P was determined by following the Denige's method as modified by Truog and Meyer [1929]. Four successive extractions were made with each soil. A correction was made in each case, for the amount of soluble phosphate which might be present in the soil. The amount which came out in the sulphuric acid extract subtracted from the sum which was added and present in the soil before treatment gives the amount fixed, which makes it possible to calculate the capacity of the soil to fix P in a difficultly available form.

Hardy and Folletsmith [1931] determined the amount of aluminium and iron oxides uncombined with silica by Schmelev's Alizarin adsorption method. Their determination was based on the fact that the iron oxide in the soil can absorb alizarin sulphonate only before ignition, whilst the alumina gel can absorb alizarin sulphonate only after ignition. It was felt desirable to examine as to how far the capacities of the soil for fixation of phosphates change after ignition. Accordingly, experiments in fixation of phosphates were carried out with non-ignited as well as ignited soil materials (about 1·5 gm. of material was heated to the maximum temperature of a Bunsen burner for about 15 minutes). For the sake of comparison and for understanding the nature of substances in the soil which are responsible for phosphate fixation, measurements were carried out with some typical minerals containing iron and aluminium and titanium (ignited and non-ignited), and similar experiments were also carried out with gels of SiO_2, TiO_2, Al_2O_3, and Fe_2O_3

Preparation of gels of TiO_2, Al_2O_3, Fe_2O_3 and SiO_2

TiO_2 gel.—It was prepared by hydrolysing extra pure $TiCl_4$ in a large volume of water and was electrodialysed in a three-chambered Pauli's pattern electrodialysing apparatus, circulating cold water through anodic and cathodic chambers. The dialysis was continued till the anode was free from chloride ion.

Fe_2O_3 gel.—In a concentrated solution of pure ferric chloride, ammonia was added till the gelation was complete. The whole mass was dialysed by passing distilled water for a long time till the dialysate was free from chloride ion.

Al_2O_3 gel.—It was similarly prepared from aluminium chloride.

SiO_2 gel.—In a concentrated solution of sodium silicate, hydrochloric acid was added till the gelation was complete. The whole mass was electrodialysed in a three-chambered Pauli's pattern electrodialysing apparatus, circulating cold water through the anodic and cathodic chambers. The dialysis was continued till the anode was free from chloride ion.

After dialysis all the gels were dried at 50°C. in an electric oven.

Results

Table IV shows the results on the phosphate fixation with non-ignited soils and with gels of TiO_2, SiO_2, Al_2O_3 and Fe_2O_3, whilst Table V exhibits the corresponding data with ignited materials. In these tables the 4th, 5th, 6th and 7th columns represent the amount of P coming into solution in the 1st 2nd, 3rd and 4th individual extractions, whilst the 8th column represents the total amount of P coming into solution.

The results in Table IV show that with non-ignited soils, in some cases, e.g. Nagpur and Midnapur, the amount of phosphates which is made non-available increases as the depth of the profile increases. In the case of Cannanore, on the other hand, the amount of phosphate, which is non-available, decreases with the depth. In general, however, it may be said that the amount of phosphate fixed up shows a maximum value at an intermediate depth.

Of the minerals studied, ilmenite possesses maximum power of phosphate fixation, the next in order being haematite. Of the gels studied, Fe_2O_3 and TiO_2 possess a very high power of phosphate fixation, that by Al_2O_3 being also considerable.

The experiments in the present paper suggest that the fixation of phosphates by the soil takes place in three stages. A tentative suggestion can be offered based on the idea of Mattson and Karlson [1938]*. The PO_4 ions which come out of the soil in the first extraction is a measure of the 'extra-micellar' PO_4. The sum total of those which comes out in subsequent extractions is a measure of the 'saloid-bound' PO_4, and the phosphate which remains permanently fixed measures the 'colloid-bound' phosphate. This grouping of absorbed phosphates into three categories is similar to the ideas of Heck [1934].

* The idea of micellar-binding of PO_4 ions is similar to the considerations put forward by Mukherjee as early as 1921 [Mukherjee, 1921].

Tables IV and V show the comparison between the quantity of P fixed by ignited and non-ignited soils. It will be found that there is no general correlation between the quantity of phosphates fixed by non-ignited and ignited soils.

Table VI shows the relation between p.p.m. of P fixed by the non-ignited soils and percentage sesquioxides in hydrochloric acid extracts [Van Bemmelen, 1877 *et seq.*]. The p.p.m. of P fixed as shown by the first extraction was plotted against the percentages of sesquioxides in HCl extract (Fig. 1). It will be seen from the curve that, in general, the p.p.m. of phosphorus fixed increases with the percentages of sesquioxides in HCl extract. Similar observations have also been made by Romine and Metzger [1939].

TABLE IV

Amount of P coming into solution when the phosphate-treated non-ignited soil is shaken with 0·002 N sulphuric acid solution

Locality	Soil No.	Depth	p.p.m. of P coming into solution from the treated soil less p.p.m. of P coming into solution in each corresponding extraction from the untreated soil (500 p.p.m. of P was added)				
			1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Dacca Farm (Bengal)	1p	0–6 in.	252	52	35	32	371
	2p	6 in.—2 ft. 3 in.	193	61	45	23	322
	3p	2 ft. 3 in.—4 ft.	148	111	48	43	350
Himayatsagar (Hyderabad)	18p	0—3 in.	311	62	35	25	433
	19p	3 in.—1 ft. 6 in.	252	64	45	44	395
	20p	1 ft. 6 in.—4 ft.	323	75	17	29	444
	21p	1 ft. 6 in.—4 ft.	405	36	11	9	461
Telankheri (1), Nagpur (C. P.)	23p	0—2 ft.	85	62	56	29	232
	24p	2 ft.—2 ft. 6 in.	68	55	48	40	211
Telankheri (2), Nagpur (C. P.)	26p	13 ft.—16 ft.	450	1	17	26	494
	27p	16 ft.—21 ft.	397	33	9	31	407
Chandkhuri Farm, Raipur (C. P.)	33p	0—4 in.	236	66	48	48	398
	34p	4 in.—1 ft. 5 in.	160	89	60	42	351
	35p	1 ft. 5 in.—4 ft.	178	90	56	50	374
Puzathi, Cannanore (Madras)	48p	16 ft.—30 ft.	200	97	49	9	355
	50p	Below 30 ft.	342	46	40	5	433
	51p	Below 30 ft.	333	51	52	50	486
Nilgiri hills (1), (3,000 ft. a. s. l.)	53p	0—1 ft. 8 in.	216	51	53	45	365
	54p	1 ft. 8 in.—3 ft.	205	54	59	43	361
	55p	Below 54p	219	87	49	36	391
Nilgiri hills (2), (5,000 ft. a.s. l.)	56p	0—1 ft. 2 in.	94	53	40	34	221
	57p	1 ft. 2 in.—2 ft.	71	61	41	34	207
	58p	2 ft.—6 ft.	141	102	86	79	308

TABLE IV—*concld.*

Locality	Soil No.	Depth	p.p.m. of P coming into solution from the treated soil less p.p.m. of P coming into solution in each corresponding extraction from the untreated soil (500 p.p.m. of P was added)				
			1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Nilgiri hills (3), (7,000 ft. a. s. l.)	59p	0—1 ft.	116	84	46	45	291
	60p	1 ft.—3 ft.	12	19	26	24	81
	61p	3 ft.—4 ft. 6 in.	38	48	40	38	164
	62p	4 ft. 6 in.—6 ft.	36	46	43	18	143
Stambhalaguruva, Guntur (Madras)	67p	0—8 in.	299	41	27	33	400
	68p	in.—1 ft. 2 in.	231	50	57	3	331
	69p	1 ft. 2 in.—5 ft.	265	164	36	28	493
Hathwara, Manbhum, Chota Nagpur (Orissa).	81p	0—1 ft. 6 in.	240	62	41	41	384
	82p	1ft 6in.—2 ft. 3 in.	166	69	62	46	343
	83p	2 ft. 3 in.—3 ft. 6 in.	125	67	58	36	376
	84p	3 ft. 6 in.—4 ft. 11in.	117	59	57	41	274
	85p	Below 4 ft. 11 in.	242	51	50	36	379
Kapileswar, Bhubaneswar (Orissa)	103p	0—2 ft. 11 in.	179	80	63	54	376
	104p	2 ft. 11 in.—4 ft.	171	86	57	41	355
	105p	Below 4 ft.	286	61	29	33	409
Lalgarh, Midnapur (Bengal)	112p	0—4 in.	213	145	82	46	486
	113p	4 in.—3 ft. 4 in.	196	102	90	49	437
	114p	3 ft. 4 in.—4 ft.	275	71	49	31	426
	115p	7 ft.—8 ft.	236	59	42	39	376
Black cotton soils	114	...	251	123	84	34	492
	118	...	123	170	115	43	451
	119	...	294	38	16	27	377
Kaolin (American)	...	...	386	49	24	24	483
Kaolin (Indian)	...	...	382	37	23	23	463
Bauxite (American)	...	...	193	61	50	25	329
Bauxite (Indian)	...	...	180	50	41	14	285
Limonite	...	...	248	26	20	19	313
Magnetite	...	...	260	21	20	19	320
Haematite	...	...	213	12	11	6	242
Ilmenite	...	...	90	18	17	6	131
Iron oxide gel	...	...	0	0	0	0	0
Alumina gel	...	...	65	50	35	30	180
Titania gel	...	...	0	0	0	0	0
Silica gel	...	...	316	52	37	15	419

Table V

Amount of P coming into solution when the phosphate-treated ignited soil is shaken with 0·002 N *sulphuric acid solution*

Locality	Soil No.	p.p.m. of P coming into solution from the treated soils less p.p.m. of P coming into solution in each corresponding extraction from the untreated soil (500 p.p.m. of P was added).				
		1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Dacca Farm (Bengal)	1p	273	[illegible]	36	21	427
	2p	275	[illegible]	31	31	406
	3p	222	96	82	48	448
Himayatsagar (Hyderabad)	18p	189	66	37	20	312
	19p	186	105	53	32	376
	20p	305	172	112	5	494
	21p	212	57	25	21	315
Telankheri (1), Nagpur (C. P.)	23p	264	89	35	48	436
	24p	217	50	35	30	332
Telankheri (2), Nagpur (C. P.)	26p	468	19	10	2	499
	27p	387	50	11	10	458
Chandkhuri Farm, Raipur (C. P.)	33p	248	99	56	31	424
	34p	210	100	47	45	402
	35p	100	98	69	59	326
Puzathi, Cannanore (Madras)	48p	274	72	36	35	417
	50p	318	65	45	35	460
	51p	308	80	20	12	420
Nilgiri hills (1) (3,000 ft. a. s. l.)	53p	224	61	28	21	334
	54p	222	64	49	46	381
	55p	279	63	41	41	424
Nilrgii hills (2) (5,000 ft. a. s. l.)	56p	144	76	45	34	299
	57p	[illegible]	48	51	45	242
	58p	150	94	51	41	316
Nilgiri hills (3), (7,000 ft. a. s. l.) (Madras)	59p	120	72	58	49	299
	60p	80	86	72	44	282
	61p	70	76	72	58	276
	62p	125	98	65	44	332
Stambhalaguruva, Guntur (Madras)	67p	243	40	62	0	345
	68p	246	43	30	29	347
	69p	240	50	50	20	360

TABLE V—*contd.*

Locality	Soil No.	p.p.m. of P coming into solution from the treated soils less p.p.m. of P coming into solution from the untreated soil in each corresponding extractions (500 p.p.m. of P was added)				
		1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Hathwara, Manbhum (Bihar)	81p	198	68	52	43	361
	82p	253	40	50	37	380
	83p	181	45	42	37	304
	84p	135	86	52	37	310
	85p	236	85	43	35	399
Kapileswar, Bhubaneswar (Orissa)	103p	337	65	42	34	478
	104p	216	87	48	39	390
	105p	296	59	25	30	410
Lalgarh, Midnapur (Bengal)	112p	221	98	76	67	462
	113p	229	54	37	43	364
	114p	278	49	50	49	426
	115p	263	49	48	36	396
Black cotton soils	114	203	67	62	60	392
	118	124	109	61	36	330
	119	218	105	35	30	368
Kaolin (American)*		380	78	25	10	493
Kaolin (India)		380	39	25	25	469
Bauxite		190	60	52	27	329
Limonite		250	24	20	19	313
Magnetite		262	19	19	18	313
Haematite*		200	18	17	9	244
Ilmenite		85	27	20	9	141

* Chemical compositions of these minerals are as follows :—

	SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	TiO_2 per cent	P_2O_5 per cent
Kaolin (American)	38·69	11·88	0·10	0·60	0·00
Haematite	0·57	7·52	91·32	0·57	0·00

TABLE VI

Relation between p.p.m. of P fixed in the soil and percentage of sesquioxides in hydrochloric acid extracts

Soil No.	p.p.m. of P fixed as shown by 1st extraction	p.p.m. of P fixed as shown by 4 extractions	Percentage sesquioxides in HCl extract**
1p . . .	248	129	20·50
2p . . .	307	178	12·84
3p . . .	352	150	19·13
18p . . .	189	67	9·75
19p . . .	148	105	7·08
20p . . .	177	56	11·03
21p . . .	95	19	15·41
23p . . .	415	268	43·77
24p . . .	432	289	43·26
26p . . .	50	6	20·00
27p . . .	103	30	26·29
33p . . .	264	102	44·67
34p . . .	340	149	46·68
35p . . .	322	126	56·90
48p . . .	300	145	16·62
50p . . .	158	67	6·03
51p . . .	167	14	7·62
53p . . .	284	135	20·28
54p . . .	295	139	22·29
55p . . .	281	109	19·95
56p . . .	406	229	24·56
57p . . .	419	293	18·72

** These values include the percentages of TiO_2 and P_2O_5 in the HCl extract besides those of Al_2O_3 and Fe_2O_3.

TABLE VI—*contd.*

Soil No.	p.p.m. of P as shown by 1st extraction	p.p.m. of P as shown by 4 extractions	Percentage sesquioxides in HCl extract
58p . . .	359	192	7·92
59p . . .	384	209	37·58
60p . . .	488	419	52·58
61p . . .	462	336	54·84
62p . . .	464	357	45·69
67p . . .	201	100	9·65
68p . . .	269	169	17·55
69p . .	235	7	19·67
81p . . .	260	116	8·09
84p . . .	383	226	13·30
85p . . .	258	121	15·83

Practical aspect of fixation of phosphates

While the subject of phosphate fixation is important from theoretical considerations, indicating the nature of the fixation, it has its practical applications. The fundamental question with which the common agriculturist is concerned is the determination of the minimum amount of phosphatic fertilizers necessary to add to a particular soil in order to establish and maintain in the soil solution a concentration of phosphate sufficient to meet the needs of the standing crop. The chief interest of the farmer, therefore, centres round the determination of that portion of a standard phosphate treatment which remains unfixed or, being fixed, is yet able to rapidly re-enter the soil solution as the nutrient is withdrawn from the medium by the roots of the standing crop. Phosphate fixation in a moderate degree may indeed be looked upon as a benefit to the farmer, for it then becomes a means of withholding the nutrient against leaching. When, however, fixation is excessive an application of water-soluble phosphates becomes so firmly held in the soil that plants may have difficulties in obtaining quantities required for their growth and development. It is clear that so far as crop production is considered, phosphate fixation is not invariably an unmitigated evil.

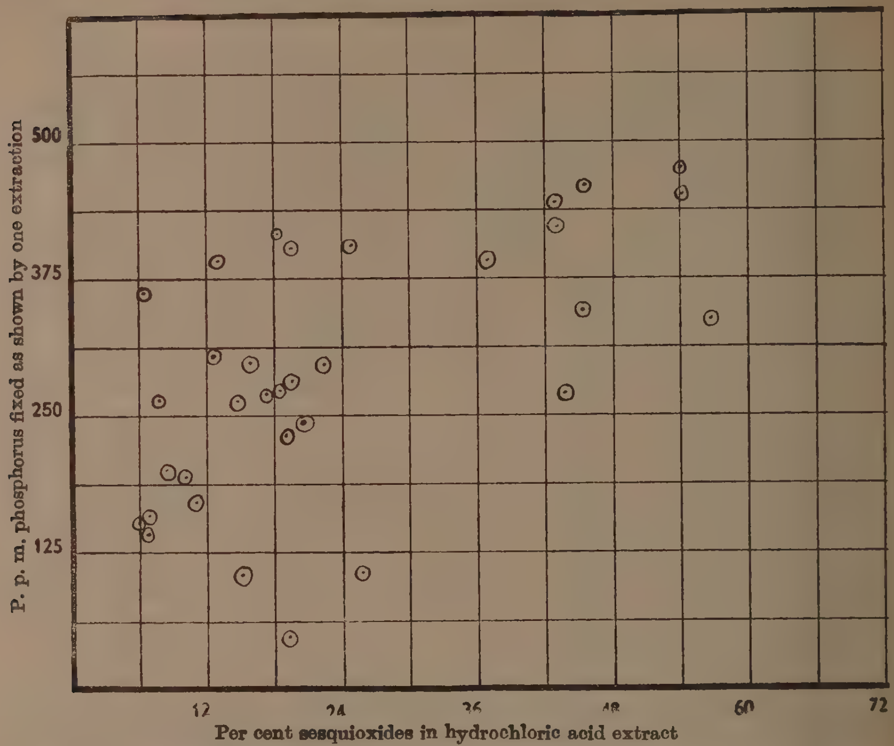

FIG. 1. Variation of the p.p.m. of phosphorus fixed in the soils (as shown by one extraction) with the percentages sesquioxides in hydrochloric acid extracts (vide Table VI)

Summary

1. Fixation of phosphates by Indian red soils has been studied from two points of view :—

Section I.—Section I deals with a study on the uptake of phosphates from phosphate solutions by soils after shaking the mixture of the soil and the phosphate solution for a certain time.

Section II.—This section deals with a study on the fixation of phosphates by soils from phosphate solutions when the latter are brought into equilibrium with the soil by evaporation to dryness.

2. It is found, in general, that up to about 30 minutes time of shaking, the phosphate fixation proceeds at a rapid rate, the rate gradually falling off, becoming almost constant after two hours and remaining thus for the remainder of the period during which observations were made.

3. When equilibrium is brought about by shaking, it is found that Indian bauxite possesses the maximum power of retention of phosphates, whilst kaolin possesses none. The capacity of magnetite to retain phosphate is not appreciable, whilst the hydrated iron-bearing mineral limonite, and the

titanium-bearing mineral ilmenite possess almost the same power of retaining phosphates.

4. The absorption of phosphates by shaking is highest in the case of the profile samples from Nilgiri hills (2) and Nilgiri hills (3), and is considerably greater than in the case of ordinary iron-bearing or titanium-bearing minerals.

5. When equilibrium is brought about by evaporation of the mixture to dryness, ilmenite shows maximum power of phosphate fixation, next in order being haematite. Of the gels studied, Fe_2O_3 and TiO_2 possess a very high power of phosphate fixation and that by Al_2O_3 is also considerable.

6. There is no correlation between the quantity of phosphate fixed by ignited and non-ignited soils.

7. In general, the p.p.m. of phosphorus fixed increases with the percentage of sesquioxides in hydrochloric acid extract of the soils.

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STUDIES ON INDIAN RED SOILS

III. GENERAL MORPHOLOGICAL CHARACTERISTICS OF SOME PROFILES

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IN connection with the investigations at the Dacca University, on the nature of red soils of India, financed by the Imperial Council of Agricultural Research, monoliths and profile samples were collected from Chota Nagpur, Orissa, Assam, Bengal and southern India. In selecting the sites care was taken to obtain the most representative red soils of the locality. Profiles from the places enumerated below have been examined, and those marked with asterisk as representing typical areas have been described and discussed in the present paper.

A. Chota Nagpur

1. Hathwara Farm, Purulia, Manbhum
*2. Putida, Chybasa, Singhbhum (Table I)
3. Ratu, Ranchi
*4. Baralota, Daltonganj, Palamau (Table II)

B. Orissa

5. Tangi, Kapilas Road, Cuttack
6. Dhanmandal, Cuttack
*7. Kapileswar, Bhubaneswar (Table III)
*8. Jhinkartangi, Khurda town (Table IV)

C. Assam

*9. Mawphlang, Khasi hills (Table V)
10. Cherrapunji, Khasi hills
11. Burrabazar, Khasi hills, Shillong
*12. Upper Chandmari, Tura, Garo hills (Table VI)
*13. Nongpoh, Khasi hills (Table VII)
14. Uzanbazar, Gauhati
15. Divisional Forest Office compound, Tura, Garo hills
16. Babupura, Tura, Garo hills

D. Bengal

*17. Lalgarh, Midnapur (Table VIII)
18. Khudsoule Mouza, Bankura
*19. Sultanganj, Bogra (Table IX)
20. Khetur Road, Barind Tract, Rajshahi
21. Bhowal Gajari Garh, Jaydebpur, Dacca

E. Southern India

*22. Sankey's Tank area, Bangalore (Table X)

23. Navayur, Coimbatore
24. Sravanampatti, Hillock, Coimbatore (Black cotton soil)
25. Sravanampatti Hillock, Coimbatore (Red soil)
26. Kadirur village, Tellicherry, Malabar
*27. Talap village, Cannanore, Malabar (Table XI)
*28. Pasumalai, Madura (Table XII)
29. Maddilipalayam village, Vizagapatam (Grey soil)
30. Maddilipalayam village, Vizagapatam (Red soil)

} Madras province

DESCRIPTIONS OF TYPICAL RED SOIL FROM VARIOUS TRACTS

A. SOILS OF CHOTA NAGPUR

The soils of the plateau of Chota Nagpur have been formed on various types of rocks, the most commonly occurring types being unclassified crystalline gneiss. As Schokalsky [1932] has pointed out, the original gneiss of Chota Nagpur and the rocks of other ages, occurring in some places of the plateau, are overlaid by red soil, the greater part of which is of a sandy clayey composition. On the flat-topped summits maize, millets and pulses are cultivated. The slopes are worked into many terraces, and well-irrigated rice may be cultivated on these and also in valleys. It was found on the whole that the red soils occurring in the different districts of Chota Nagpur are very similar. The coarse, gritty red soil is frequently quarried for making roads and roofs of houses. In general red soils are found to exist on the higher slopes of hills, brownish soils at intermediate layers and blackish soils lower down. The blackish soil is suitable for cultivation and crop production. Throughout the range of Chota Nagpur considerable gully and sheet erosion are noticeable.

TABLE I

Soil profile No. P (D. U.) 33 Put.

1. *Locality* : Putida (Chybasa), Singhbhum, Chota Nagpur
2. *Climate*—
   Temperature : Maximum 115°F. (end of May) ; minimum 85°F. (end of December)
   Rainfall (in.) : Jan. 0·64, Feb. 1·68, Mar. 0·69, Apr. 0·89, May 1·77, June 4·45, July 10·67, Aug. 13·04, Sept. 7·65, Oct. 2·39, Nov. 1·33, Dec. 0·34 : Total 45·54.
3. *Altitude* : 762 ft. a. s. l.
4. *Surface feature* : Undulating. Profile was taken on a mild slope. On the northern side of the pit is Munduburn hills
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Thin grass, *palash*, *biri* leaf, *asan* tree, *mahua* (*Bassia latifolia*)
   Common crops : Sugarcane, *aman* paddy, groundnut, maize, soyabean, gram, wheat
6. *Soil-water conditions*—
   Free surface drainage at the place where the profile was taken, but in adjacent areas waterlogging was observed
   Water table : Maximum depth, 18 ft. in summer ; minimum depth 14 ft. in rainy season

7. *Character of parent material* : Dalma trap and Mergui volcanics

Horizon	Thickness	Description of each horizon			Sapmle depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. . .	Greyish black	Sandy loam .	Friable and granular	0-1 ft. . .	Greyish black soil mixed with gravels and boulders with interpenetration of plant roots, mixed with yellowish clay-like material
2	1 ft.-2 ft. 9 in.	Reddish .	Clayey loam	Granular .	1 ft.-2 ft. 9 in.	Concretionary layer mixed with boulders and gravels
3	Below 2 ft. 9 in.	Yellowish red	Rocky .	Honeycombed and compact	2 ft. 9 in.-4 ft.	Rocky material often containing yellowish substances, entrapped in the vesicles and considerable quantities of dark reddish pieces of slate-like material

Table II

Soil profile No. P (D. U.) 35 Bar.

1. *Locality* : Baralota, Daltonganj, Palamau district, Chota Nagpur
2. *Climate*—

Temperature : Maximum 115°F. (end of May); minimum 85°F. (end of December)

Rainfall (in.) : Jan. 0·99, Feb. 1·28, Mar. 0·37, April 0·43, May 0·59, June 3·39, July 15·53, Aug. 13·29, Sept. 5·91, Oct. 2·33, Nov. 0·75, Dec. 0·36 : Total 45·22

3. *Altitude* : 726 ft. a. s. l.
4. *Surface features* : Undulating. Profile taken on a gentle slope
5. *Nature of natural and cropping vegetation*—

Natural vegetation : *Palash* and *sal* trees

Crops :

(*a*) Monsoon—Paddy, maize, *rahar* (*Cajanus cajan*), and groundnut

(*b*) *Rabi*—Wheat, gram, barley

6. *Soil-water conditions*—

Free surface drainage

Water table : Maximum depth 35-40 ft. in summer ; minimum depth 20-25 ft. in rainy season

7. *Character of parent material* : Limestones, shales and slates

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. 1 in. .	Dark red .	Clayey .	Loose granular	0-1 ft. 1 in. .	Dark red soils mixed with gravels
2	1 ft. 1 in.-2 ft. 9 in.	Red . .	Clayey .	Gritty . .	1 ft. 1 in.-2 ft. 9 in.	Red soil mixed with large quantities of pebbles and concretionary materials
3	2 ft. 9 in.-4 ft.	Red . .	Sandy loam	Gritty . .	2 ft 9 in.-4 ft.	Ditto, but more compact
Sample from another place in the vicinity from where it was already quarried						
4	4 ft.-5 ft. .	Yellow. .	Sandy . .	Loose . .	4 ft.-5 ft. .	Yellowish sandy material with admixtures of whitish substance

B. Soils of Orissa

The province of Orissa including the Mahanadi river delta represents an absolute flatness, coated with alluvial deposits. The alluvial bed, red in colour, in some places rests on low-level laterite. An inspection of several areas suggests that the soils of the province of Orissa belong at some places to the red and some places to the lateritic varieties, generally low-level laterites.

Table III

Soil profile No. P (D. U.) 38 Kap.

1. *Locality* : Kapileswar village, 1 mile west of Bhubaneswar town
2. *Climate*—
   Temperature : Maximum 106°F.-110°F. (3rd week of May) ; minimum 52°F. (end of December)
   Rainfall (in.) : Jan. nil, Feb. 4·26, Mar. 1·52, Apr. 2·00, May 3·60, June 5·87, July 22·17, Aug. 12·28, Sept. 12·53, Oct. 3·60, Nov. nil, Dec. nil : Total 67·83
3. *Altitude* : 108 ft. a. s. l.
4. *Surface feature* : Undulating, the profile taken in a quarry on a gentle slope from Udaygiri to Gogua rivulet
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Nux-vomica, banian, mangoes, *pipal* (*Ficus religiosus*), *madan masta*
   Crops : Paddy, *mung* (*Phaseolus radiatus*), arum, sugarcane
6. *Soil-water conditions* —
   Free surface drainage and free percolations through the laterite stones
   Water-table : Maximum depth 25 ft. in summer ; minimum depth 6 ft. in rainy season
7. *Character of parent material* : Gneiss

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-2 ft. 11 in. .	Reddish brown	Loamy .	Loose granular	0-2 ft. 11 in. .	Soil mixed with root and pebbles, the colour of the soil becoming gradually deeper red from top downwards
2	2 ft. 11 in. below (up to 30 ft. approx.)	Bright red, mottled with yellow, white and black	Rocky .	Honeycombed	2 ft. 11 in.-4 ft.	Honeycombed laterite rock with yellow and white clay material entrapped in the vesicles
	Sample from another place from the digging of a well					
3	30 ft. downwards	Whitish clayey	...	...	...	Locally known as '*tiluk mati*' (used in painting foreheads)

TABLE IV

Soil profile No. P (D. U.) 39 Jhin.

1. *Locality* : Jhinkartangi, 2 miles south of Khurda town
2. *Climate* —
   Temperature : Maximum 106°F. (3rd week of May) ; minimum 50°F. (end of December)
   Rainfall (in.) : Jan. 0·40, Feb. 0·74, Mar. 0·90, April 0·81, May 3·35, June 9·04, July 12·89, Aug. 12·84, Sept. 10·14, Oct. 6·05, Nov. 1·76, Dec. 0·37 : Total 59·29
3. *Altitude* : 50 ft.-100 ft. a.s.l.
4. *Surface features* : Profile taken from a quarry on the top of a ridge called 'Jhinkar Tangi' on the northern side of the Barunai Hill and close to the hill
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Nux-vomica, *kendu*, mango, jak tree, tamarind, banian, *peepal*, plum
   Cropping vegetation : Paddy, *mung*, *kalai*, lentil, sugarcane, *rahar*, *kulthi*, potato, pumpkin, *karela*
6. *Soil-water conditions*—
   Free surface drainage and impeded percolation in the stony layers. The top soil always permits free percolation
   Water-table : Maximum depth 20 ft. in summer ; minimum depth 0 ft. in the rainy season
7. *Character of the parent material* : Gneiss

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. . .	Brownish red	Clayey loam .	Loose granular	0-1 ft. . .	Soil mixed with gravels
2	1 ft.-2 ft. .	Ditto (the reddish tinge being deeper than in the 1st layer)	Do. .	Do. .	1 ft.-2 ft. .	Do.
3	2 ft.-8 ft. 6 in.	Bright red .	Do. .	Gravelly .	2 ft.-8 ft. 6 in.	Laterite murrum
4	8 ft. 6 in. below	Red mottled with yellow and whitish colour	Rocky .	Honeycombed laterite rock	8 ft. 6 in.-10 ft.	The top 6 in. of the laterite rock is softer and easier of cutting than of the bottom which gradually becomes harder as the depth increases
		Sample from another place from the digging of a well				
5	30 ft.-50 ft. .	Yellow .	Clayey .			
6	50 ft. below .	White .	Clayey .			

The two types of laterites occur in these places : firstly the type of laterite murrum and secondly the type of laterite rock. The former is quarried for the construction of roads and roofs and the latter for cutting into the forms

of bricks (usually 9 in. × 15 in. × 24 in. slabs) for the construction of buildings. The soft laterite murrum contains considerable quantities of plant food materials and has often been found quite suitable for the growth of paddy, oranges and roses. A well (45 ft.) dug in the Khurda Forest Office (Puri district) showed soil characteristics as follows :—

1. 0-15 ft.—A layer of red laterite murrum
2. 15-30 ft.—Red honeycombed laterite rock
3. 30-32 ft.—Yellow clay
4. 32-35 ft.—White clay
5. 35-45 ft.—Clay of deep grey colour

The reddish honeycombed laterite rocky mass turns black after exposure to the sun for some time. The depth of the laterite murrum layers varies at different places considerably. So also do the layers of hard laterite and yellow, white and cement-coloured clays. In fact some of the layers are entirely absent from some of the places.

As in the case of Bihar, considerable gully and sheet erosion was noticeable in Orissa.

At Khurda town the higher plots were found to be mostly sandy at the top and clayey underneath, some plots having hard rock beds on the surface. Consequently these lands sometimes become impervious to agricultural implements and have very low moisture-retention capacities. They are practically worthless for cultivation, especially during hot weather, though paddy may be grown to some extent during the rains.

Soils of Assam

The Shillong plateau (Khasi and Jaintia hills)

The Shillong plateau rises steeply from the Surma valley to an average height of 4,000 ft. and gradually slopes towards the Brahmaputra valley in a succession of low ranges covered with dense evergreen forests. Even in the hottest weather, the temperature of Shillong never records above 80°F., and there is often frost in winter. Snowfall is rare, because there is no precipitation of moisture in the cold season. The average rainfall of Shillong town is 80 in. per year. On the other hand, at Cherapunjee, a station on the southern end of the Khasi hills, about 30 miles from Shillong, the average annual rainfall is 426 in. The general characteristics of soil types in the Khasi hills are of red soils on the top of hills, yellowish soils at intermediate layers and black soil at the bottom.

In Cherapunjee, in most places, sandstone occurs below the surface up to 20-25 ft. approximately. Frequently the sandstone occurs as outcrops, and even in sandy soil moisture is retained. Below the sandstone layer, at depths approximately 35-40 ft. below the surface, limestone frequently occurs, whilst at some places near the surface, deposits of coal occur up to 3 ft. depth.

Near about the Shillong plateau below the hard soil layer honeycombed laterite rocky mass is however fairly soft. Pieces of boulders, mostly composed of granites are very common in all places of the Khasi hills. Soil erosion occurs extensively.

To quote the words of Schokalsky [1932], 'The Shillong plateau is composed of Archean quartzites and schists, interstratified with trap and overlaid

by sandstones of the cretaceous period, which in their turn dip under eocene nummulitic limestone. In origin the plateau is more closely allied to the Deccan than to the Himalayas; it is supposed to be a part of the Deccan, precisely the north-east extremity of the latter, which was afterwards separated from it by the subsidence of Bengal. This view is confirmed by its gneisses and schists extending throughout the latter, as well as Bihar, Orissa, etc. And in the character of its soils, Shillong belongs to the Deccan. Under the conditions of a tropical humid climate on the plateau corresponding soil types should develop'.

The soils on the Shillong plateau are generally known as lateritic. But on a considerable area of the plateau nummulitic limestones form the upper layer of the sediments. In such areas we should be inclined to presume the occurrence of red soil, in places which are not infrequently developed from the products of decomposition of limestone [Schokalsky, 1932]. South of the Shillong plateau extends a vast area known as Madhupur jungle; Oldham [1893] holds the view that it is composed of alluvial red-coloured clays.

Coal, limestone and iron are the principal minerals found in Khasi and Jaintia hills. Cretaceous coal is found near Mawphlang, tertiary coal in Cherra, and limestone is found on the surface of Khasi and Jaintia hills, especially at Khasimora on the south slopes of the Khasi hills. Corundum is also found in the district in small quantities. Iron is available at Cherra and Lylinkot. Mineral oil has been found near Cherra.

The flora of the Khasi hills is extremely rich and has a luxuriant growth. Hooker [1854] collected, within 10 miles of Cherra, over 2,000 flowering plants, with varieties of orchids, balsams and wild roses.

Paddy and potatoes grow very well in the Khasi and Jaintia hills. Cotton, however, does not do so well.

Garo hills

The soil types in the Garo hills, from the morphological point of view, appear to be different from the typical lateritic soils of Orissa. It appears that the removal of clayey matter by erosion from the soil types is the cause of the sandy nature of the soil. The white sandy material of the soil seems to be contaminated with substances of the nature of kaolin which makes this white material a valuable substance for the construction of roads.

Various types of red soils * occur at different places in the Garo hills area most of which are sandy in nature. In the Government Farm areas cowdung is usually applied as manure. Ordinary cultivators, however, do not apply any manure, and after one or two years, they find the land unproductive and shift to another place.

Common crops grown in the Garo hills are maize, rice, cotton, and chilli. Pineapples also grow very well. The usual method of farming in the Garo hills is what is known as *jhum* cultivation, i.e. cutting of the forest and setting fire to the trees. When the jungles have been cleared in this way any of the above crops can be grown. After two years of crop production, however, the land becomes unproductive, and it appears that instead of keeping the land fallow, as is usually done, the production of leguminous crops, like pulses, might increase the productivity of the land.

* The local name for the red soil is *agichak*

TABLE V

Soil profile No. P (D. U.) 41 Kha.

1. *Locality* : Mawphlang, Khasi hills, Assam
2. *Climate*—
   Temperature : Maximum 80°F. (March-April) ; minimum 24°F. (Dec.-Jan.)
   Rainfall (in.) : Jan. 0·52, Feb. 1·04, Mar. 2·17, April 5·24, May 11·14, June 34·88, July 34·00, Aug. 22·52, Sept. 15·86, Oct. 9·55, Nov. 1·49, Dec. 0·26 : Total 138·67
3. *Altitude* : 6,000 ft. a.s.l.
4. *Surface features* : Sloping towards south
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Pine, wild oak, rhododendrons
   Cropping vegetation : Potatoes, maize, millets, soy-bean
6. *Soil-water conditions* : Free surface drainage
7. *Character of parent material* : Shillong series

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-6 in. .	Brownish grey	Loamy .	Loose granular	0-6 in. . .	Interpenetration of roots
2	6 in.-1 ft. 3 in.	Reddish grey	Loamy .	Do. .	6 in.-1 ft. 3 in.	Do.
3	1 ft. 3 in.-2 ft. 1 in.	Red . .	Stiff clayey .	Granular .	1 ft. 3 in.-2 ft. 1 in.	Mixed with some whitish materials. Occasionally some burrow holes were noticed. The soil remains moist even in dry weather.
4	2 ft. 1 in.-4 ft.	Deep red .	...	...	2 ft. 1 in.-4 ft.	Mixed with concretionary compact materials, intermingled occasionally with whitish material.
5	Parent materials	...	...	...	... ...	Pieces of sandstone, quartz, and iron concretions.

TABLE VI

Soil profile No. P (D. U.) 44 Kha.

1. *Locality* : Nongpoh district, Khasi and Jaintia hills, Assam
2. *Climate.*—
   Temperature : Maximum 77°F.-84°F. (April-Sept.) ; minimum 57°F.-58°F. (Dec.-Jan.)
   Rainfall (in.) : Total 70 in. approximately
3. *Altitude* : 1,800 ft. a. s. l.
4. *Surface features* : Undulating, profile taken from a cutting on a hilly slope
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Sal, poma, *Ficus* (different kinds), plantains
   Cropping vegetation : Paddy, cotton, pulses

Soil-water conditions : Free surface drainage

7. *Character of parent material* : Granites

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-6 in. . .	Reddish grey	Loamy .	Granular .	0-6 in. . .	Penetration of roots
2	6 in.-3 ft. 6 in.	Yellowish red	Loamy .	Columnar .	6 in.-3 ft. 6 in.	Containing small iron nodules
3	3 ft. 6 in.-4 ft. 2 in.	Blackish red	Clayey .	Concretionary	3 ft. 6 in. 4 ft. 2 in.	Soft concretions
4	4 ft. 2 in.-6 ft.	Red . .	Clayey .	Do.	4 ft. 2 in.-6 ft.	Do.
5	Parent material	...	...	...	...	Granites

TABLE VII

Soil profile No. P (D. U.) 46 Gar.

1. *Locality* : Upper Chandmari, Tura, Garo hills, one mile north of Inspection Bungalow
2. *Climate*—
   Temperature : Maximum 85°F.-87°F. (March-September) ; minimum 53°F.-54°F. (January)
   Rainfall (in.) : Jan. 0·41, Feb. 0·89, Mar. 2·09, April 6·92, May 16·36, June 25·39, July 24·81, Aug. 21·87, Sept. 19·18, Oct. 8·25, Nov. 0·73, Dec. 0·11 : Total 127·01
3. *Altitude* : 1,300 ft. a.s.l.
4. *Surface features* : Hilly and undulating, profile taken on the slope of a hillock
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Sal, bamboo, tamarind, mango, jak fruit
   Cropping vegetation : Cotton, paddy, chilli, maize
6. *Soil-water conditions*—
   Free surface drainage
   Water-table : Maximum depth 10-12 ft. in dry season ; minimum depth 3-4 ft. in wet season
7. *Character of parent material* : Pab sandstones

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-3 in. .	Grey . .	Sandy . .	Nutty and friable.	0-3 in. . .	Penetration of roots
2	3 in.-1 ft. 8 in.	Grey mixed with mottled red	Sandy . .	Friable .	3 in.-1 ft. 8 in.	Easily crumbles down, mixed with whitish material
3	1 ft. 8 in.-2 ft. 8 in.	Light red mixed with black and white	Sandy . .	Friable rocky mass	1 ft. 8 in.-2 ft. 8 in.	Seems to be of the nature of dead rocks
4	2 ft. 8 in.-4 ft.	White mixed with (occasionally) black and pinkish matter	Sandy . .	Crumbly rocky mass	2 ft. 8 in.-4 ft.	Mixed with quartz particles

Soils of Bengal

(i) Western Bengal

Table VIII

Soil profile No. P (D. U.) 40 Lal.

1. *Locality*: Lalgarh, 27 miles N.-N.-W. of Midnapur
2. *Climate*—
   Temperature: Maximum 100°F.-105°F. (last week of April); minimum 45°F.-50°F. (first week of January)
   Rainfall (in.): Jan. 1·31, Feb. 0·80, Mar. 0·45, April 1·62, May 0·54, June 6·69, July 7·98, Aug. 6·97, Sept. 4·35, Oct. 2·63, Nov. 1·65, Dec. 0·68 : Total 34·67
3. *Altitude*: 239 ft. a.s.l.
4. *Surface features*: Undulating; profile taken on a mild slope
5. *Nature of natural and cropping vegetation*—
   Natural vegetation: Shrubby weeds, lantana plants are common
   Cropping vegetation: Aus and aman paddy, castor, maize and *juar*
6. *Soil-water conditions*—
   Free surface drainage, impeded percolation
   Water-table: Maximum depth 100 ft. in summer; minimum depth 10 ft. in rainy season
7. *Character of parent material*: Cuddalore, warkalli, karewa, older alluvium, laterite

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-4 in.	Brownish red	Sandy loam	Loose laterite murrum	0-4 in.	Gravelly
2	4 in.-3 ft. 4 in.	Yellowish red	Rocky	Compact laterite murrum	4 in.-3 ft. 4 in.	Compact and gravelly
3	3 ft. 4 in. below	Brownish	Sandy loam	Granular	3 ft. 4 in.-4 ft.	Brownish friable material
4	7 ft. below	Yellowish	Do.	Do.	7 ft.-8 ft.	Yellowish material probably the decomposed material
	Samples taken from other places					
	0-8 in.	Yellowish red	Sandy loam	Granular	...	
	Bed of R. Cossye	Blackish	Clayey	Slaty	...	Slate-like material found at the bed of the partially dried up R. Cossye
	45 ft. below	Yellowish	Clayey	...	...	From the diggings of a well at Mailda village Farm, between Lalgarh and Midnapur town

The local name for the laterite murrum at Midnapur is *kankar mati*. The loose or soft laterite murrum contains a considerable amount of plant food materials as indicated by the big trees growing on it. In some places it was noticed that the cultivators remove the top of the murrum layer and agriculture is practised on the yellowish clay at the bottom.

The red soils of the district of Bankura seem to be very similar in morphological features to those occurring in the adjacent district of Manbhum in Chota Nagpur. Rice is the main crop which is grown in Bankura; sugarcane and *til* (*Sesamum indicum*) also do fairly well. Irrigation is necessary here during the dry periods.

(ii) Northern Bengal : The red soil of the Barind tract

The so-called Barind area is an extensive tract extending from the Godagari Ghat on the west up to the western bank of the Karotoya river. Rice grows very well in this area. At the Khetur Road the surface soil, locally known as *balka mati*, sets to a stiff mass in wet weather. On the other hand, the subsoil at Khetur Road, locally known as *lal mati* does not set to a stiff mass in wet weather. An interesting fact about the soil type at Bogra was that while red soil occurs on the western bank of the Karotoya river, on the eastern bank of the same river whitish alluvial soil occurs on which extensive cultivation of rice, jute and pulses is carried out. The Barind tract is similar in morphological features to the lateritic soils of Eastern Bengal.

TABLE IX

Soil profile No. P (D. U.) 49 Bog.

1. *Locality* : Sultanganj, Bogra, Bengal, western bank of Karotoya river. 2 furlongs S.-E. of Government Sericultural Farm
2. *Climate*—
   Temperature : Maximum 96°F. (in April) ; minimum 52°F. (in January)
   Rainfall (in.) : Jan. 0·38, Feb. 0·78, Mar. 1·24, April 2·27, May 8·50, June 14·03, July 13·06, Aug. 13·29, Sept. 11·67, Oct. 4·96, Nov. 0·74, Dec. 0·05 : Total 70·97
3. *Altitude* : 55 ft. a.s.l.
4. *Surface features* : Even
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Palm, date, banian, mango, mulberry and bamboo
   Cropping vegetation : Rice grown on the yellow subsoil below the red layer
6. *Soil-water conditions*—
   Free surface drainage
   Water-table : Maximum depth 25-30 ft. ; minimum depth 4-5 ft.
7. *Character of parent material* : Recent deposit

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft.	Brown	Clayey loam	Fine granular	0-1 ft.	Penetration of roots
2	1 ft.-2 ft.	Reddish brown	Loamy	Compact	1 ft.-2 ft.	Mixed with black iron concretionary material, increasing at greater depth
3	2 ft. below	Red	Loamy	Do.	2 ft.-4 ft.	Mixed with black iron concretionary material, increasing at greater depth, but more compact
4	12 ft.-25 ft. (app.)	Yellow	Clayey	...	12 ft.-25 ft. (app.)	From the diggings of a well
5	25 ft.-30 ft. (app.)	Yellow	Sandy	...	25 ft.-30 ft. (app.)	Do.
6	30 ft. below	Slaty black	Sandy	...	30 ft. below	Do.

Soils of Southern India

Profile samples were collected from Bangalore and from eastern, western and southern parts of Madras province. Soils of these parts of India mostly consist of red soils formed on Archean and metamorphic rocks and on coastal alluvium. Along the extreme part of the west coast in the Malabar district, laterite soils formed on low level laterites are found in abundance. Occasionally there are black soils of medium and light texture. The parent material of all these soil types are mostly granites.

Table X

Soil profile No. P (D. U.) 53 Bang.

1. *Locality* : Sankey's reservoir area, Bangalore city
2. *Climate*—
   Temperature : Maximum 93°F. (in April) ; minimum 57°F. (in January)
   Rainfall (in.) : Jan. 0·26, Feb. 0·17, Mar. 0·50, April 1·33, May 4·36, June 2·89, July 4·18, Aug. 5·38, Sept. 6·98, Oct. 5·90, Nov. 2·94, Dec. 0·48 : Total 35·37
3. *Altitude* : 3,000 ft. a.s.l.
4. *Surface features* : Undulating samples from a fissure mainly by gully erosion
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Mangoes, cashew nut, toddy palms
   Cropping vegetation : *Ragi*, horsegram and *juar*
6. *Soil-water conditions*—
   Free surface drainage
   Water-table : Maximum depth 20 ft.-30 ft. in winter ; minimum depth varies greatly
7. *Character of parent material* : Gneissic granites

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-3 ft. 6 in.	Red	Loamy	Granular	0-3 ft. 6 in.	
2	3 ft. 6 in.-4 ft. 6 in.	Red	Loamy	Do.	3 ft. 6 in.-4 ft. 6 in.	Mixed with white gravels
3	4 ft. 6 in.-6 ft.	Yellowish red	Loamy	Gravelly	4 ft. 6 in.-6 ft.	Mixed with numerous white gravels and more compact than layer '2'
4	6 ft.-7 ft.	Yellow	Sandy loam	Rocky	6 ft.-7 ft.	Compact rocky mass
5	Parent rock	...	...	...	...	

Table XI

Soil profile No. P (D. U.) 58 Can.

1. *Locality* : Talap village, about 1 1/4 mile from Cannanore station, Malabar district.

2. *Climate*—
   Temperature : Maximum 90°F. (in May) ; minimum 70°F. (in January)
   Rainfall (in.) : Jan. 0·25, Feb. 0·26, March 0·18, April 2·15, May 7·78, June 38·22, July 35·07, Aug. 18·83, Sept. 8·63, Oct. 7·95, Nov. 3·67, Dec. 0·61 : Total 123·60
3. *Altitude* : 50 ft. a.s.l.
4. *Surface features* : Undulating, profile taken from a quarry
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Coconut, mango, jak
   Cropping vegetation : Paddy, tapioca, *ragi* and pepper
6. *Soil-water conditions*—
   Maximum depth of water-table 30 ft. in winter ; minimum depth of water-table 15-20 ft. in the rainy season
7. *Character of parent material* : Granites

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-6 in.	Greyish red	Gravelly loam	Gravelly	0-6 in.	
2	6 in.-5 ft. 5 in.	Red	Do.	Do.	6 in.-5 ft. 6 in.	Murrum, laterite, mixed with plenty of nodular iron concretionary pieces
3	Below 5 ft. 5 in.	Red mixed with yellowish white material	...	Rocky	5 ft. 6 in.-6 ft.	Honeycombed lateritic rock, yellowish material entrapped in the vesicles
4	Parent materials	...	...	...	...	

Table XII

Soil profile No. P (D. U.) 59 Pasu.

1. *Locality* : Pasumalai Farm area, Madura district
2. *Climate* —
   Temperature : Maximum 100°F. (in May) ; minimum 69° F. (in January)
   Rainfall (in.) : Jan. 0·60, Feb. 0·36, Mar. 0·51, April 2·03, May 2·89, June 1·37, July 1·92, Aug. 4·25, Sept. 5·11, Oct. 7·82, Nov. 4·95, Dec. 1·77 : Total 33·58
3. *Altitude* : 450 ft. a.s.l.
4. *Surface features* : Profile taken from a freshly dug pit at the foot of a small hill
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : *Babul* trees (*Acacia*), palms, coconuts and prickly pears
   Cropping vegetation : Paddy, *juar*, cotton, groundnut, gingelly sesame

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. 2 in.	Brownish red	Sandy loam	Granular	0-1 ft. 2 in.	Mixed with pebbles
2	1 ft. 2 in.-4 ft. 3 in.	Red	Do.	Gravelly	1 ft. 2 in.-4 ft. 3 in.	Mixed with large quantities of pebbles and often nodular iron concretions
3	4 ft. 3 in.-8 ft. (app.)	Yellowish white	Sandy	Rocky	4 ft. 3 in.-6 ft.	Decomposed felspars, mostly cemented by iron concretions
4	8 ft.-40 ft. (app.)	Mixed black and white	...	...	8 ft.-40 ft. (app.)	Rocky sample taken from the diggings of a well. Decomposed felspars mixed occasionally with *kankars*, i.e. calcareous materials
5	40 ft. below (app.)	Parent material	...	...	...	

It appears on the whole that the soil types of the Madras province are similar to the soil types occurring in Assam. Regarding the nature of the red soils in Madras province, Leather [1898] has pointed out that generally in these soils the amount of lime is small or only moderate, magnesia is not high and phosphoric acid is uniformly low. On the other hand, the proportion of ferric oxide and alumina is usually high. Indeed their composition is in many respects similar to the lateritic soils, the chief feature of dissimilarity being in their respective proportions of phosphoric acid. Whilst the laterite soil contained very varying amounts of this valuable plant food, its proportion in these red soils were very uniform, the extreme variations being between 0·5 and 0·9 per cent.

A good deal of variations on the general nature and the distributions of the soils in the area were observed, there were distinct differences with respect to the depth of the soil and thus with distributions of soil inclusions, such as gypsums, calcium carbonate, quartz, etc.

The Malabar coast of the Madras province, like Bengal, is a part of India very rich in rainfall. Malabar is, therefore, a place of luxuriant tropical vegetation. The distribution of rainfall is fairly regular throughout the year. The dry season of the year does not last long enough to injure the vegetation and the amount of moisture accumulated in the soil during the rainy season is quite sufficient. A survey of the surface soils of the Malabar district has been made by Viswanath and Ramasubrahmanyan [1928].

DISCUSSION

It appears from what has been stated above that from the morphological point of view, the red soils studied can be divided into three broad types :—

(1) Red loams : characterized by argillaceous soil with a cloddy structure and the presence of only a few concretionary material, e.g. Purulia (Bihar), Palamau (Bihar), Mawphlang (Khasi hills, Assam), Uzanbazar (Gauhati, Assam), Tura (Garo hills, Assam), Bankura (Bengal), Khetur Road (Rajshahi, Bengal), Bangalore (South India), Jaydebpur (Bengal), Coimbatore (S. India), Vizagapatam (S. India).

2. Red earths : where the top soil is loose and friable but rich in concretions of a sesquioxide character, e.g. Ranchi (Bihar), Dhanmandal (Cuttack, Orissa), Nongpoh (Khasi hills, Assam), Bogra (Bengal), Pasumalai (Madura, S. India).

3. Laterite soils : where the surface is more akin to red earths, but with the presence of a definite layer of vesicular laterite rock below, e.g. Chybasa (Bihar), Kapileswar (Bhubaneswar, Orissa), Kapilas Road (Cuttack, Orissa), Khurda town (Puri, Orissa), Midnapur (Bengal), Tellichery (Malabar district), Cannanore (Malabar district).

Speaking generally, the profile characteristics of the red soils of Bengal seem to be of the same nature as those of Orissa. The soils of the Malabar coast are similar in morphological features to those occurring in Orissa and Midnapur. The profiles of loamy red soil of the southern parts of the Madras province seem to be similar in nature to those occurring in the province of Assam. The red soils of Bangalore appear to be mostly detrital laterites and, in general, their morphological features are similar to the ordinary red soils occurring in Coimbatore.

Nature of closely occurring red and black soils

The black cotton soil of Coimbatore occurs very close to a red soil area. The occurrence of such dissimilar red soils in close proximity has been discussed by many workers, but it appears that the most plausible explanation is that given by Marchand [1924] who discusses at length the question of the occurrence of dissimilar soils associated with similar rocks in South Africa. He points out that the texture of the soil 'will depend on the relative proportions of kaolin, silicic acid and ferric hydroxide, and these proportions are not the same for all rocks of similar mineralogical make up.' The presence of iron compounds in the rocks makes the resulting soil more open and easily drained. Moreover, sometimes an admixture of sandy material perhaps from an adjacent quartzite or sandstone takes place and the resulting soil is a red heavy loam. The mineralogical examination of these profiles has been undertaken. Mention may be made here of the work of Viswanath [1939] on the occurrence of red and black soils in close localities in the Madras province, including Coimbatore. He points out that the black soils have a much higher base-exchange capacity than the red soils. The silica-alumina ratio of the clay fractions are also higher. Compared to red soils, they are rich in calcium carbonate, possess a higher degree of colloidality, are more adhesive, expand greatly when wet and contract considerably when dry. These observations agree with those made by the author while working with two closely occurring types of red and black soils of South Africa [Raychaudhuri, 1936 ; Basu and Sirur, 1938]. (Cp. also the recently published work of Nagelschmidt, Desai and Muir [1940]).

Fox's view of Indian laterite and lateritic soils

Discussing the nature of laterite and lateritic soils occurring in India, Fox [1936] has suggested that while the term 'laterite' can be used in a comprehensive sense, the more finished product should be precisely termed 'laterite', whilst the red soils of the Malabar coast which Buchanan originally designated as 'laterite' must in the main be regarded as lithomargic laterite, meaning thereby a comparatively unfinished product. The problem

on the nature of Indian laterites and lateritic soils has been summarized and discussed by Raychaudhuri [1937], and a detailed examination of the physico-chemical properties of the profile samples has been undertaken with a view to finding out the nature of these soil types, especially in the light of the views expressed by Fox.

Honeycombed laterite rocky mass

Discussing the occurrence of the honeycombed masses, Sen [1939] has expressed the view 'that in India a soil may be termed laterite when a morphological examination reveals these profile characteristics, especially in the presence of cellular concretions of iron irrespective of the soil's chemical composition'. Thus Sen has suggested that in the study of laterite soils the soil chemist or the pedologist should confine his attention to the surface soil, leaving the study of the underlying honeycombed mass to the geologist. On the whole it appears that the separation of the iron oxide in the form of nodules and the gradual cementation of the latter to form a consolidated honeycombed mass is one of the characteristic features of this type of soil formation. The so-called 'murrum laterite' may thus be an intermediate stage in the formation of 'rock laterite'. There appears to be no general relationship of the formation of the iron crust with the ground water level or with the annual rainfall except that the iron crust should have formed under alternate conditions of desiccation and saturation.

Summary

The morphological features of some profiles of red soils from Chota Nagpur, Orissa, Assam, Bengal, and South India have been examined. The nature of these soil types has been discussed.

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STUDIES ON INDIAN RED SOILS

IV. NATURE OF THE WEATHERING COMPLEX AS DETERMINED BY THE VAN BEMMELEN-HISSINK METHOD OF HYDROCHLORIC ACID EXTRACT

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VAN BEMMELEN [1877, 1879, 1888, 1904] studied the soil silicates in detail and showed that they can be divided into two groups :—

(1) The unweathered portion which occurs even as crystals in clays and to which definite chemical formulae can be assigned, and

(2) The weathered portion which he considered to be absorption complex of the form SiO_2, pAl_2O_3, qFe_2O_3, rCaO, etc. and not definite minerals or compounds to which definite chemical formulae can be assigned.

He divided this latter group into two classes*:

(*a*) Those completely decomposed by boiling hydrochloric acid (Silicate A), and

(*b*) Those resistant to this treatment but decomposed by hot concentrated sulphuric acid (Silicate B).

Van Bemmelen established the fact that the bases held in silicate B are not on the whole exchangeable and that silicate A displays colloidal properties in a more marked degree than silicate B. The work of Van Bemmelen suggests that silicate A is the reactive body present in the soil. As Russell [1937] has pointed out, however, this distinction between silicate A and B is not sharp. Thus it is to be pointed out that hydrochloric acid decomposes appreciable quantities of many parent rocks, e.g. basalt, often some silicate B, though not as vigorously as sulphuric acid, and it does not decompose all the material possessing base-exchange capacity in the soil. Hydrochloric acid extract has, however, been often used by workers all over the world in order to find out the nature of the so-called weathering complex.

Sigmond [1938] has pointed out that the silicic acid liberated from the silicates by the actoin of hydrochloric acid, although insoluble in that acid, nevertheless forms an integral part of the hydrochloric acid extract. The silicic acid should be therefore dissolved in potassium hydroxide or sodium hydroxide and added to the SiO_2 soluble in hydrochloric acid.

In the course of the work at the Dacca University on the nature of the lateritic and red soils of India, it was felt desirable to examine the nature of the active part of the weathering complex as defined by Van Bemmelen (Van Bemmelen's silicate A). Determinations of the percentages of the different constituents of soils that are dissolved by boiling hydrochloric acid and of the alkali-soluble silica in the residue after extraction with hydrochloric acid were accordingly undertaken.

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* Harrasowitz [Sigmond, 1938] applies the term 'allophane' to materials of group (*a*) and kaolin to materials of goup (*b*).

Experimental

Procedure for the determination of silica, alumina and iron oxide

The analyses of the percentages of constituents of soils dissolved by boiling concentrated hydrochloric acid were carried out by following essentially Van Bemmelen-Sigmond's method as modified by A. E. A. [1931]. 25 gm. of soil (2-mm. sieve) treated with 250 c.c. of concentrated hydrochloric acid (sp. gr. 1·16) in 600-c.c. tall beaker, covered with a clock glass, were boiled gently for one hour, cooled, filtered and the residue lixiviated with hot water till it was free from acid. This filtrate (filtrate A) was made up to 500 c.c. From this 100 c.c. aliquot was taken in a casserole, evaporated in a water-bath after addition of a few c.c. of strong HNO_3. When evaporation was complete, a few c.c. of strong HCl were added. After this, when evaporation was complete, the dried residue was heated for about six hours at about 120°C. to dehydrate the silica and then the mass was dissolved with gentle stirring, by means of dilute hydrochloric acid (approximately $2N$), filtered through a gravimetric filter paper and washed till free from chloride. The filtrate (filtrate B) was made up to 250 c.c. The filter paper with the residue was ignited for the determination of SiO_2, whilst alumina and iron oxide were determined in filtrate B.

Determination of the alkali-soluble silica

In the residue after hydrochloric acid extraction, the alkali-soluble silica was determined by following essentially the method devised by Sigmond [1928]. The insoluble residue after hydrochloric acid extraction was dried on a water-bath. The filter paper was ignited and added to the insoluble residue. By this process, colloidal silica became insoluble in dilute alkali. To avoid this care was taken so that only a small quantity of the insoluble residue from the decantation reached the filter paper. To dissolve the soluble silica, 250 c.c. of potassium hydroxide solution of sp. gr. 1·04 was added and gently heated at 55°C. for five minutes in an Erlenmeyer flask and lixiviation with water was continued until there was no alkaline reaction. Silica was then determined from the solution. The results of analyses of some typical profiles of red soils collected fron various parts of India are given in Table I.

Table I

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/Fe_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	Fe_2O_3			
Bengal—Dacca Farm	0-6 in.	5·03	0·112	5·142	12·96	6·96	0·669	0·499	2·917
	6 in.-2 ft. 3 in.	10·81	0·050	10·860	5·90	6·75	3·106	1·797	1·345
	2 ft. 3 in.-4 ft.	12·13	0·125	12·255	9·81	9·23	2·108	1·317	1·665
Suri, Birbhum	0-1 ft.	5·24	0·034	5·274	2·72	2·44	3·271	2·080	1·746
	1 ft.-1 ft. 6 in.	8·00	0·023	8·023	6·35	4·60	2·563	1·644	1·799
	* Below 13 ft.	(K) 15·62	0·164	15·784	5·14	8·97	5·178	2·449	0 901
	** Below 13 ft.	(K) 7·81	0·091	7·901	2·73	3·92	4·882	2·546	1 091

* This is a yellow clay from a well at depth below 13 ft. (very near from where the other two samples were collected).

** This is a yellowish white clay from a well at depth below 13 ft. This was heaped by the side of the well and grass was growing on it. The sample was taken from the heap 1 in.-5 in. after removing the top 1 in. to get rid of grass roots, etc.

TABLE I—*contd.*

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent: Alkali-soluble	SiO_2 per cent: Acid-soluble	SiO_2 per cent: Total soluble	Sesquioxides in HCl extract (per cent): Al_2O_3	Sesquioxides in HCl extract (per cent): F_2O_3	SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/F_2O_3 (molecular)
Bengal (Barind tract)—									
Bogra	0-1 ft.	4·62	Very slight	4·62	0·88	2·11	8·855	3·500	6·533
	1 ft.-2 ft.	6·06	0·061	6·121	3·02	1·08	3·436	2·798	4·385
	2 ft.-4 ft.	12·26	0·082	12·342	5·85	2·52	3·575	2·804	2·297
	* 12 ft.-15 ft.	8·37	0·083	8·453	2·39	4·99	6·589	2·674	0·685
	** 25 ft.-30 ft.	8·51	1·462	9·972	3·99	4·39	4·236	2·490	1·425
Khetur Road, Rajshahi	0-1 ft. 10 in.	11·05	0·161	11·211	2·72	2·26	6·983	4·562	1·888
	1 ft. 10 in.-2 ft. 3 in.	14·95	0·069	15·019	6·89	5·46	3·695	1·630	1·979
	2 ft. 3 in.-4 ft.	15·69	0·054	15·744	6·79	5·26	3·928	2·629	2·071
Hyderabad—									
Bidar	0-1 ft.	34·29	0·055	34·345	19·14	28·56	3·042	1·582	1·063
	1 ft.-3 ft.	28·36	0·043	28·403	18·49	13·46	2·603	1·797	2·283
	3 ft.-4 ft.	20·62	0·211	20·831	24·14	18·20	1·462	0·997	2·144
Himayeth sagar	0-3 in.	6·49	0·067	6·557	5·99	3·32	1·856	1·381	2·917
	3 in.-1 ft. 6 in.	16·53	0·039	16·569	5·50	1·55	5·105	4·347	5·724
	† 1 ft. 6 in.-4 ft.	11·40	0·104	11·504	2·51	7·86	7·764	2·644	0·516
	†† 1 ft. 6 in.-4 ft.	17·73	0·067	17·797	6·97	7·74	4·328	2·670	1·455
Hyderabad—									
Alisagar	0-1 ft.	1·62	0·065	1·685	2·90	8·20	1·054	0·384	0·571
	‡ 1 ft. downwards	12·86	0·110	12·970	10·70	8·60	2·049	1·368	2·011
Central Provinces—									
Telankheri, Nagpur	‡‡ 0-2 in.	21·06	1·072	27·132	35·41	8·02	1·299	1·140	7·137
	‡‡ 2 in.-2 ft. 6 in.	37·19	0·004	37·194	35·21	7·73	1·790	1·576	7·362
	‡‡‡ 13 ft.-16 ft.	49·02	0·072	49·092	9·96	9·66	8·352	5·219	1·666
	‡‡‡‡ 16 ft.-21 ft.	44·96	0·113	45·073	19·54	6·53	3·909	3·241	4·826

* This is the approximate depth, taken from the digging of a well very near to the place from where the other three samples were collected.

** This is the next layer of the soil marked with * from the digging of the same well.

†† This is a whitish material occurring occasionally in the same horizon of the soil as is marked with †. Said to be due to the decomposition of pigmatite.

‡ This is the second horizon of the soil usually extending 5 to 6 ft. below the surface.

‡‡‡ Decomposed rock from the side of a hill cuttings about 50 yards away from the hill on which the sample marked with‡‡ have been collected.

‡‡‡‡ Greenish grey layer of probably more than 5 ft. in depth underlying the sample marked with ‡‡‡

TABLE I—*contd.*

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/Fe_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	Fe_2O_3			
Central Provinces—									
Chandkhuri Farm, Raipur	0-4 in. .	4·49	0·208	4·695	23·04	21·35	0·346	0·220	1·745
	4 in.-1 ft. 5 in. .	9·25	0·265	0·515	24·35	22·05	0·663	0·425	1·784
	1 ft. 5 in.-4 ft. .	5·83	0·049	5·879	32·04	24·57	0·311	0·214	2·107
Labhandi . .	* 0-8 in. . .	5·67	0·081	5·751	16·25	8·76	0·600	0·450	2·998
	**8 ft.-10 ft. .	4·32	0·065	4·385	15·77	5·31	0·472	0·390	4·808
Bihar (Chota Nagpur)—									
Putida, Chybasa	0-1 ft. . .	35·39	0·091	35·681	7·22	6·54	8·374	5·367	1·787
	1 ft.-2 ft. 9 in. .	39·89	0·042	39·932	11·32	7·19	8·375	5·368	1·805
Assam—									
Uzanbazar, Gauhati	0-6 in. . .	12·84	0·112	12·952	5·46	7·16	4·021	2·219	1·232
	6 in.-11 ft. .	13·09	0·113	13·203	4·70	10·82	4·766	1·965	0·702
	11 ft.-16 ft. .	14·75	0·068	14·818	12·79	7·24	1·965	1·455	2·852
	†† Below 16 ft..	14·89	0·102	14·992	5·37	2·87	4·734	3·559	3·029
Tura, Garo hills	0-3 in. . .	11·26	0·102	11·362	7·84	19·47	2·459	0·969	0·651
	3 in.-1 ft. 8 in.	10·68	0·092	10·772	8·99	9·99	2·032	1·204	1·453
	1 ft. 8 in.-2 ft. 8 in.	11·32	0·093	11·413	6·61	15·61	2·926	1·189	0·685
	2 ft. 8 in.-4 ft. .	7·78	0·101	7·881	4·06	3·99	3·294	2·048	1·645
Assam—									
Nongpoh, Khasi and Jaintia hills	0-6 in. . .	2·44	0·081	2·521	5·73	7·67	0·746	0·408	1·208
	6 in.-3 ft. 6 in. .	15·22	0·089	15·309	11·12	7·60	2·344	1·641	2·365
	3 ft. 6 in.-4 ft. 2 in.	15·09	0·087	15·177	12·15	8·41	2·117	1·485	2·335
	4 ft. 2 in.-6 ft.	14·18	0·012	14·192	13·66	9·92	1·760	0·633	2·228
Madras (Malabar coast)—									
Kakat, Cannanore	0-1 ft. 3 in. .	7·82	0·116	7·936	15·45	13·18	0·871	0·570	1·895
	1 ft. 3 in.-4 ft. .	9·77	0·142	9·912	13·46	25·01	1·248	0·581	0·870
Puzathi, Cannanore	16 ft.-30 ft. .	5·29	0·276	5·566	8·33	8·21	1·334	0·732	1·641
	‡ Below 30 ft. .	6·99	0·276	7·266	2·98	3·02	4·134	2·515	1·561
	‡‡ Below 30 ft.	7·02	0·068	7·088	3·89	3·66	3·088	1·952	1·718

** This is a yellowish white clay occurring further down the darkish clay which occurs just below the soil marked with*

†† This layer extends up to the parent material.

‡‡ White substance, often with fossilized roots occurring as lumps and layers in and between the same layer as marked with ‡ and the layer above that.

TABLE I—*contd.*

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/F_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	Fe_2O_3			
Madras (Nilgiri hills)—									
3,000 ft. a.s.l.	0-1 ft. 8 in.	34·43	0·128	34·558	8·60	11·42	6·811	3·740	1·217
	1 ft. 8 in.-3 ft.	36·67	0·079	36·749	14·63	7·62	4·260	3·221	3·101
	Below 3 ft. (to a condiserable depth)	30·21	0·038	30·248	9·06	10·73	5·659	3·266	1·365
5,000 ft. a.s.l.	0-1 ft.	7·82	0·370	8·190	13·73	10·67	1·001	0·683	2·080
	1 ft.-2 ft.	17·87	0·345	18·215	10·01	8·52	3·085	2·022	1·900
	2 ft.-6 ft.	36·51	0·017	36·527	2·68	5·00	23·11	10·72	0·866
7,000 ft. a. s. l.	0-1 ft.	6·27	0·367	6·637	14·79	22·53	0·762	0·392	1·058
	1 ft.-3 ft.	14·12	0·036	14·156	29·56	22·69	0·812	0·549	2·105
	3 ft.-4 ft. 6 in.	5·33	0·912	6·242	30·01	24·36	0·353	0·235	1·991
	4 ft.-6 in.-6 ft.	4·67	0·032	4·702	34·09	11·57	0·234	0·193	4·785
Madras—									
Stambhalaguruva, Guntur	0-8 in.	59·87	0·046	59·916	6·46	2·09	15·72	13·1	5·008
	8 in.-1 ft. 2 in.	51·00	0·057	51·057	12·53	4·78	6·907	5·59	3·366
	1 ft. 2 in.-5 ft.	52·06	0·062	52·122	14·09	5·32	6·270	5·09	3·400
Govt. Fruit Farm, Cape Comorin	0-2 ft.	9·55	0·446	9·996	11·51	1·60	1·478	1·36	11·58
	2 ft.-3 ft.	8·78	0·143	8·923	7·83	5·13	1·931	1·38	2·468

DISCUSSION

The data in the above table indicate the manner in which the percentages of Al_2O_3 and Fe_2O_3 have been washed down the profile. It will also be seen that the value SiO_2/R_2O_3 of the HCl extract of the profile samples from the following places are considerably low, e.g. Nilgiri hills (3), (7,000 ft. a.s.l.), Kakat (Cannanore, Malabar), Chandkhuri Farm (Raipur, C. P.), Labhandi (C. P.). On the other hand, the SiO_2/R_2O_3 ratios of the HCl extracts are comparatively very high in the following cases, Putida (Chybasa, Bihar), Nilgiri hills (1) (3,000 ft. a.s.l.), Stambhalaguruva (Guntur, Madras). In the case of soil samples from Nilgiri hills, the greater the height of the place from where the sample has been taken, the lower generally is the SiO_2/R_2O_3 ratio.

There is a maximum value for SiO_2/Al_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3, at an intermediate depth in the case of the profile samples from Nongpoh (Khasi and Jaintia hills) and Nilgiri hills (3), whilst with the profile from

Dacca Farm (Bengal), the value Al_2O_3/Fe_2O_3 has got a minimum at an intermediate depth, but on the other hand, in the case of the profile samples from Chandkhuri Farm (Raipur, C. P.), the value Al_2O_3/Fe_2O_3 gradually increases down the profile. Profile samples from Suri (Birbhum, Bengal), Nilgiri hills (1) (3,000 ft. a.s.l.) and Rajshahi (Bengal) show a minimum value for SiO_2/Al_2O_3 and SiO_2/R_2O_3 at an intermediate depth. The value Al_2O_3/Fe_2O_3 attains a maximum at an intermediate depth in the case of profiles from Suri (Birbhum, Bengal), and Nilgiri hills (1) (3,000 ft. a.s.l) and on the other hand Al_2O_3/Fe_2O_3 increases down the profile in the case of the profile from Rajshahi (Bengal). The profile samples from Nilgiri hills (2) show a gradual tendency for the value of Al_2O_3/Fe_2O_3 to decrease down the profile, whilst the values SiO_2/Al_2O_3 and SiO_2/R_2O_3 increase down the profile.

All the profile samples from Assam seem to contain considerable amount of unweathered materials. This is evident from the comparatively small amounts of the total quantity of materials which are dissolved by boiling hydrochloric acid and subsequently by potassium hydroxide. All the red soils of Assam appear, therefore, to be immature and may conveniently be classed, with a few exceptions, as red loams. It may also be suggested from the above data that in the case of soil samples from Nilgiri hills occurring at 7,000 ft. a. s. l., Bidar (Hyderabad), Telankheri (Nagpur, C. P.), Putida (Chybasa, Chota Nagpur), Nilgiri hills (1) (3,000 ft. a.s.l.) and Stambhalaguruva (Guntur, Madras) contain considerable proportions of alkali-soluble silica, and it may be called lithomargic laterite in the sense the term has been used by Fox [1936].

Summary

1. The percentages of silica, alumina and iron oxide dissolved from the soil by treatment with boiling hydrochloric acid and the percentages of alkali-soluble silica in the residue after extraction with hydrochloric acid have been determined.

2. Soils occurring at a height of 7,000 ft. a.s.l. in the Nilgiri hills are considerabley rich in the acid-soluble oxides of aluminium and iron. So also are the samples from Bidar (Hyderabad), Telankheri (Nagpur, C. P.), Chandkhuri Farm (Raipur, C. P.), and from Kakat (Malabar Coast).

3. The percentages of alkali-soluble silica do not show any regularity down the profiles. In the case of soils from Nilgiri hills, it is found that the greater the height from where the soils were collected the less is the quantity of alkali-soluble silica.

4. The red soils of Assam appear to be of the class of red loam, and the soils from the Barind tract are similar in nature to the soils of Assam.

5. The trends of variation of molecular ratios SiO_2/Al_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3 of HCl extract of profile samples have been brought about.

Acknowledgments

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STUDIES ON THE FIXATION OF PHOSPHATES IN INDIAN RED SOILS

I. APPLICABILITY OF TRUOG'S METHOD FOR THE DETERMINATION OF AVAILABLE PHOSPHATES

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(With two text-figures)

It is well known that tropical soils, such as those found in India, are usually rich in iron and often in titanium, and therefore, wherever any dose of phosphate is applied to such soils the phosphate is fixed by the soil in difficultly soluble forms. The study of the nutrient status of Indian soils, especially with reference to phosphate, is therefore an important one. Before any systematic study on the fixation of phosphates is undertaken, it is obviously desirable to examine the applicability of the important existing methods for the determination of available phosphates in the case of Indian soils.

The classical researches of Dyer [1894] to find out the pH of the juice of the root sap of various plants led to the development of the citric acid method for the determination of available plant nutrients, like phosphorus and potassium. Since that time a number of methods have been proposed by different workers, depending on various factors and principles. Most of these methods depend on the use of one or the other inorganic or organic acid of a particular strength as solvent for extracting the soil phosphates. Malherbe and Myburgh [1935] have compared almost all existing methods for the determination of available phosphates with South African soils. They have come to the conclusion that chemical methods are in general speedier and less expensive than Neubaur's seedling method. They have compared the applicability of the chemical methods with non-calcareous soils. In the case of calcareous soils, however, the objection raised by Das [1926] to the use of Dyer's citric acid method cannot be set aside easily. Of all the chemical methods which are in use, the one devised by Truog [1930] appears to be the most convenient and rapid. The present paper records some data on available phosphates which are obtained with some Indian red soils by Truog's method, and these data have been compared with those obtained by the acetic acid method [Williams, 1928] and also by Dyer's method [1894].

Experimental procedure

Determination of available phosphate by Truog's method

One gm. soil and 200 c.c. of $N/500$ sulphuric acid solution buffered to pH 3·0 by adding 3 gm. of ammonium sulphate per litre were shaken in a

mechanical shaker for ½ hour. This was filtered through a Whatman No. 2 filter paper, first few c.c. being discarded. To an aliquot of this 2 c.c. of ammonium molybdate-sulphuric acid solution (prepared according to Truog and Meyer [1929]) and six drops of stannous chloride solution (prepared according to Troug and Meyer [1929]) were added and the mixture made up to 100 c.c. The colour which was developed was compared with a standard within a few minutes.

Determination of available phosphate by acetic acid method

12·5 gm. of soil were placed in a beaker with 100 c.c. $N/2$ acetic acid and the mixture was stirred. After stirring several times and allowing to stand for at least two hours the supernatant liquid was poured into a filter, the filtrate being collected in a 500-c.c. measuring flask. The soil was then leached with the same acetic acid solution 30-40 c.c. at a time, until 500 c.c. were collected. To an aliquot of this, 4 c.c. ammonium molybdate-sulphuric acid solution and six drops of stannous chloride solution were added and made up to 100 c.c. The colour which developed was compared against a standard within a few minutes.

Determination of available phosphate according to Dyer's method

A weight of air-dry soil corresponding to 100 gm. of dry soil were placed in a one-litre stoppered bottle with one litre distilled water and 10 gm. of citric acid (recrystallized). The soil was allowed to remain in contact with this one per cent citric acid solution for seven days, the bottle was shaken several times each day except the last, when most of the soil settled down. After seven days the solution was filtered and 75 c.c. of the filtrate were taken in a 300-c.c. Kjeldahl flask to which 10 c.c. of concentrated hydrochloric acid were added, followed by 12 c.c. of 20 per cent sodium permanganate solution. The sides of the flasks were washed down with a little water. After standing half an hour, the contents were vigourously digested till no manganese precipitate remained. The contents were transferred to a 100-c.c. measuring flask and 4 c.c. of 10 per cent potassium ferrocyanide solution were added drop by drop with frequent shaking. Several minutes later the mixtures were titrated with ammonia until the blue colour just turned purple. 1·5 c.c. of 2 N sulphuric acid were then added and made up to the mark with water. The solution was then filtered and after discarding the first few c.c. an aliquot was taken to which 4 c.c. of ammonium molybdate-sulphuric acid solution and six drops of stannous chloride solution were added and made up to 100 c.c. and the colour was compared against a standard within a few minutes.

Experimental results and discussion

Twelve Indian red soils as described in Table I were selected. The available phosphates of these soils were determined by the three methods. The results are given in Table I.

TABLE I

Amount of phosphorus coming into solution by different methods

Locality	Depth (in.)	p. p. m. of P coming into solution by		
		Truog's method	Dyer's method	Acetic acid method
Institute area, Dacca Farm, Dacca	0—6	12	7	1·7
	6—27	17	9	2·8
Himayetnagar, Hyderabad . .	18—48	7	5	1·3
Chandkhuri Farm, Raipur, C. P.	0—4	12	6	1·5
	4—17	9	6	1·4
	17—48	11	5	1·4
Puzathi, Cannanore, Malabar .	192—360	7	4	1·1
	below 360	7	3	1·6
Nilgiri hills, 3,000 ft. a. s. l. . .	B-horizon	9	6	1·3
Nilgiri hills, 7,000 ft. a. s. l. .	12—36	14	7	2·3
	36—54	13	6	2·0
	54—72 (app.)	13	8	2·1

Fig. 1 shows graphically the relationship between the data on available phosphates of the soils by the three different methods. It will be seen that there is a fairly good degree of correlation (r between Truog's method and Dyer's method $= 0 \cdot 866$, r between Truog's method and acetic acid method $= 0 \cdot 885$, r between Dyer's and acetic acid method $= 0 \cdot 762$) between the data obtained by any two methods. It will also be seen from Table I that the amount of phosphorus coming into solution in Truog's method is almost double of that obtained by Dyer's method. This is in agreement with the observations made by Malherbe and Myburgh [1935].

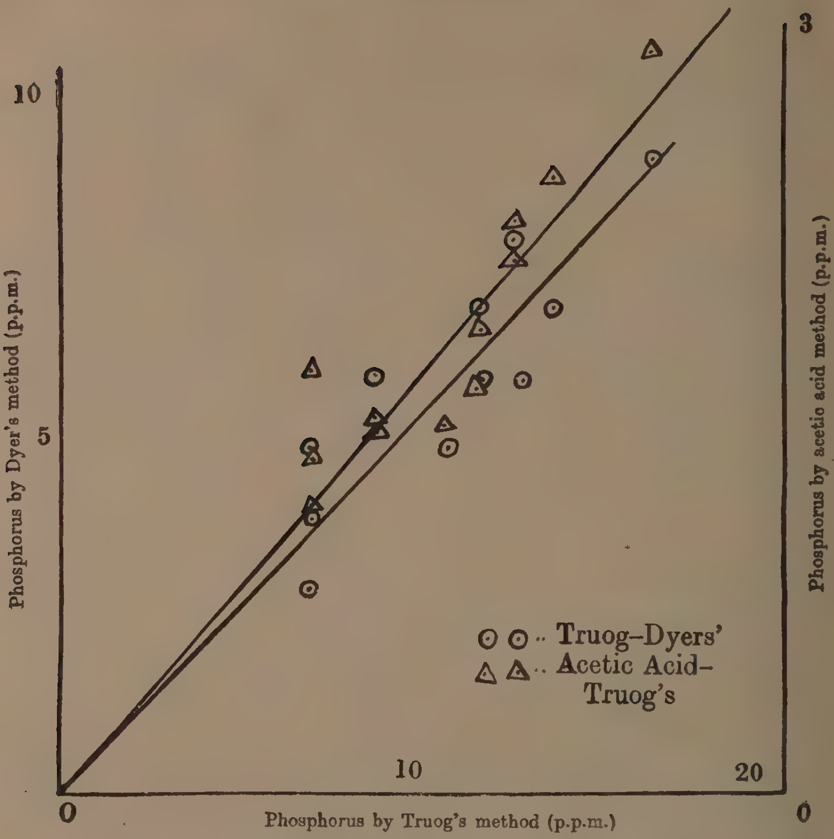

Fig. 1. Relation between the amounts of phosphorus coming into solution by Truog's method with that by Dyer's method and by acetic acid method with that by Truog's method (in case of Indian red soils)

The applicabilities of the acetic acid method and the Truog's method have also been compared with a few other non-calcareous soils of India, most of them having been collected from unmanured paddy fields. The results are given in Table II.

The last column of Table II shows the ratio of the data obtained by Truog's method and by the acetic acid method. A fair degree of correlation (r between Truog's method and the acetic acid method $=0 \cdot 992$) exists between the two sets of data and is also shown graphically in Fig. 2.

Conclusion

It follows from what has been stated above that Troug's method is equally applicable to Indian red soils. In addition it has got some advantage over other methods, namely that comparatively much less time is required for the estimation of the phosphate by Truog's method. Also, the extracting medium being a buffered solution, the pH of the soil suspension remains fairly constant.

TABLE II

Amount of phosphorus coming into solution by acetic acid method and by Truog's method

Locality	p. p. m. of P coming into solution		
	By Truog's method (T)	By acetic acid method (A)	Ratio T/A
Coimbatore 15	45	6·2	7·3
Coimbatore 3	48	6·3	7·6
Coimbatore 1	37	6·1	6·1
Gaya	46	7·0	6·6
Kanke	31	4·7	6·8
Sabour N	25	3·6	6·8
Titabari I	27	3·7	7·3
*Dacca I	311	48	6·5
*Dacca II	498	63	7·9
Kanwya	13	1·9	7·0

*These soils were taken from a flower garden which was heavily treated with phosphatic manures

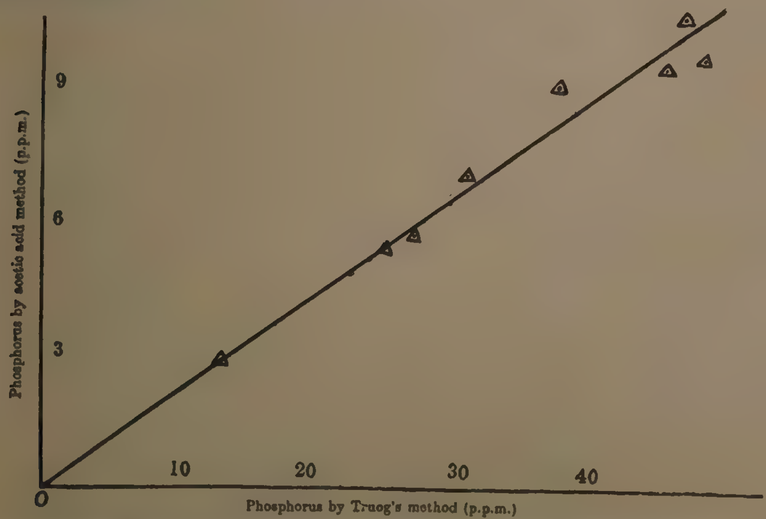

FIG 2. Relation between the amount of phosphorus coming into solution by acetic acid method and by Truog's method (in case of some rice soils)

Moreover, the amount of phosphorus (available) obtained by Truog's method is higher than that obtained by either of the other two methods, and hence Truog's method can comparatively more easily differentiate the fertilities as related to phosphate status of any two soils.

Summary

The applicability of Truog's method for the determination of available phosphates in the case of Indian red soils has been tested. It is found that as far as the Indian red soils are concerned, Truog's method for the determination of available phosphorus can easily be used, because the data obtained by Truog's method bear fair correlation to those obtained by the other two widely used methods, namely Dyer's method and the acetic acid method.

Advantages of Truog's method over the other two methods have also been pointed out.

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DETERMINATION OF RESISTANCE TO THE BLIGHT DISEASE [*MYCOSPHAERELLA RABIEI* KOVACEVSKI-*ASCOCHYTA RABIEI* (PASS.) LAB.] IN GRAM TYPES

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I. Introductory

As the result of the investigations already reported [Luthra and Bedi, 1932; Sattar, 1933; Luthra, Sattar and Bedi, 1935] the following measures were devised and recommended to farmers for the control of the blight disease of gram [*Mycosphaerella rabiei* Kovacevski=*Ascochyta rabiei* (Pass) Lab.], which is now prevalent in all the gram-growing districts of the Punjab and causes a damage of about three to four crores of rupees (£ 2.25 to £ 3 millions) annually :—

1. The sowing of disease-free seed supplied by the Agricultural Department.
2. Elimination of diseased gram material from fields by—
   (*a*) harvesting the entire crop by uprooting by hand and thus leaving fields free of infection.
   (*b*) ploughing the fields with a furrow-turning plough after the first shower of rain in summer to bury the remnants of diseased plants.
   (*c*) sweeping the threshing floors and burying or burning the collected debris.

These methods were enforced by the Agricultural Department and Revenue staff in the Attock tehsil. They stood the test for three years and proved effective against the disease. But generally they are not executed to a level of perfection collectively by all the farmers over the entire area in the affected locality. Therefore, when favourable conditions for the spread of the blight disease, i.e. low summer rainfall and high winter rainfall with many rainy days uniformly distributed, prevail, there is a widespread infection of the disease. Consequently the selection of blight-resistant gram types has been

* All the three authors are jointly responsible for the work.

considered a surer and more dependable means of combating the disease. This point has been kept in view ever since the investigation of this serious disease was started. The work on the production of resistant types was facilitated by the findings already published by the authors [Luthra, Sattar and Bedi, 1939] to the effect that the causal fungs of gram blight (*Ascochyta rabiei*) in the Punjab has no physiologic forms.

II. Experimental

A. Material and methods

Three hundred and ninety-two gram types (named types and miscellaneous collections) were obtained from various localities in India and foreign countries and their relative resistance to *Mycosphaerella rabiei* was tested. In the first instance, inoculation tests on 187 collections which were obtained by the authors directly were carried out in 1933-34, 1934-35 and 1935-36. As a result of these tests, it was observed that three types showed marked resistance. Attention was concentrated on the study of performance of these types, and inoculation experiments were continued on them. Two hundred and five samples which were supplied to the authors by the Millet Botanist, Sirsa (Punjab), were tested during 1937-38 and 1938-39. The particulars of all the collections are given in the text. The various samples were grown at the Agricultural Farm, Campbellpur, where the blight disease has been appearing in succession for several decades. About 200 plants of each sample were grown every year for the inoculation tests during the first three years. Afterwards inoculations on a larger scale (on about 5,000 plants of each selected type) were carried out. In certain experiments, the plants were grown in small plots enclosed by *sarkanda* (*Saccharum spontaneum*) screens to protect them from outside infection.

Equal numbers of plants from each sample were subjected to the following two methods of inoculation :—

(1) By spraying with a pycnospore suspension in water. Spores were taken from the fungus *M. rabiei* grown in pure cultures on oat-meal agar for three weeks. The plants were kept covered by *sarkanda* for about a week to provide moist conditions for the development of the disease. The inoculations were done in February each year, and, in order to provide heavy infection, the inoculations were repeated in March again.

(2) By spreading over the plants blighted gram plant debris chopped into small pieces, after ensuring that the stalks of the debris carried plenty of pycnidia of *M. rabiei* and that more than 70 per cent of the pyconspores contained in them were viable. The plants inoculated by this method were not covered with *sarkanda*. In this case infection occurred after rain even if it was received months after inoculation. (Previous tests had shown that the fungus carried on debris remains active for three years).

Both the methods were equally successful . Other methods of inoculation are described in their appropriate places in the text.

B. Relative resistance of the various types and collections

The results of inoculation experiments on the various types and collections of gram are summarized in Table I.

The results show that all the Indian types are highly susceptible to the disease and that out of the foreign types Pois Chiches No. 4732, No. 199, and No. 281 are very resistant. The others are either very susceptible or not so resistant as to be suitable for conditions in the northern Punjab, which are often very favourable for the development of the disease.

The three resistant types Pois Chiches Nos. 4732, 199 and 281 were selected for detailed study, and for convenience of reference these are re-named F 8, F 9 and F 10 respectively.

TABLE I

Relative resistances of types and collections of gram to Mycosphaerella rabie

Types and collections	Number of samples	Nature of infection
Indian types—		
Punjab types 1-26	26	All very susceptible and were totally killed by the disease. Type 1 was relatively less susceptible than the other types and took longer to be killed. Type 1 has white seed and is called '*Kabuli*' in Hindustani
Pusa types 1-84	84	All very susceptible and were totally killed by the disease
Nagina Bijnaur types 1-16 . .	16	Do.
Burma types 1-5	5	Do.
Shikarpur types 1-12 . . .	12	Do.
Punjab selections—		
S_2, S_4, S_5, S3A, S3B, S 7/2, S 7/3, S 7/4, S 7/5, S 7/6	10	Do.
Miscellaneous Indian types and collections—		
Red Guar Local	1	Do.
Collection from Western Tellinga division, Hyderabad	1	Do.
Gram from Raichur	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Purnbyn, Karachi 1933 (1)	1	Very susceptible and was totally killed by the disease
From Parbhawan, N. S. R.	1	Do.
Penbhatia gram	1	Do.
From Cereal Breeding Station, Nasik	1	Do.
Nasik, Hindi selected No. 1932-33	1	Do.
No. 1, W. Khandeshi	1	Do.
No. 2, W. Khandeshi	1	Do.
From Satara	1	Do.
Burma Gram from Dharwar, 1932-33	1	Do.
Dharwar Farm local gram	1	Do
Karachi special 3110 No. 5	1	Do.
Karachi special 123 No. 4	1	Do.
Karachi special 3116 No. 3	1	Do.
Karachi special No. 312 No. 2	1	Do.
Red Jacobabadi No. 1	1	Do.
Ambala A_6	1	Do.
Bhera A_3	1	Do.
Double R	1	Do.
Ferozepore samples	4	Do.
F 1	1	Do.
Kiloi 1	1	Do.
Lahore C_6	1	Do.
12 L D/2A, 12 L D/2B, 12 L D/3, 14 L D/2(a) and 14 L D/2(b)	5	Do.
Multan A_2	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Bengal Malda 2 samples . . .	2	Very susceptible and was totally killed by the disease
Bharatpur samples Nos. 2, 5, 22 . Bharatpur Local 1, 3 and 4 . .	6	Do.
Cawnpore	1	Do.
Central Provinces samples Nos. 1, 28, 34, 62, 288, 351 and 352	7	Do.
Coimbatore samples 19, 416, 468 and 482	4	Do. C 416 less susceptible than others though ultimately severely attacked
Coimbatore selection Nos. 4, 5, 6, 8, 9 & 11	6	All very susceptible and were totally killed by the disease C S 11 less susceptible than others though ultimately severely attacked
Indore sample	1	Very susceptible and was totally killed by the disease
Karachi samples	2	Do.
Nadiad Sirsa sample . . .	1	Do.
Nadiad sample No. 2 . . .	1	Do.
Pondicherry sample	1	Do.
Frontier types 1-8	8	Do.
Parachinar S_1 and S_2 . . .	2	Do.
Tarnab sample	1	Do.
Sabour local sample . . .	1	Do.
Sabour types 5, 6 and 7 . . .	3	Do.
Cuttack, Orissa S_1 and S_2 . . .	2	Do.
Sukkur White S_1 and S_2 . . .	2	Do.
Amritsar S_1	1	Do.
Bangalore sample . . .	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Isthana S_1	1	Very susceptible and totally killed by the disease
Viramgam sample	1	Do.
Bagalkot sample	1	Do.
Sholapur S_1 and S_2	2	Do.
Broch sample	1	Do.
Gadag S_1 and S_2	2	Do.
Khandesh E sample . . .	1	Do.
Poona sample	1	Do.
Ahmedabad sample	1	Do.
Foreign types—		
Roma types 1-3	3	All very susceptible and were totally killed by the disease. Roma No. 1 was relatively less susceptible than the other two types. This is like the Punjab white '*Kabuli*'
Catterda Ambulante di Agricole Napoli Nos. 1-8	8	All very susceptible and were totally killed by the disease. No. 7 was relatively less susceptible
Stazione Agaria Experimentale Bari, Nos.1-4	4	Very susceptible and was totally killed by the disease
Pois Chiches No. 281 . . .	1	Very resistant. This is now called in the Punjab F 10
Pois Chi hes No. 199 . . .	1	Very resistant. This is now called in the Punj ıb F 9
Pois Chiches No. 180 . . .	1	Fairly resistant
Pois Chiches No. 4732 . . .	1	Very resistant. This has been named F 8 and has been selected for introduction in the Punjab and is being multiplied
Pois Chiches Tobanda . . .	1	Susceptible and killed by the diseas
Pois Chiches Ghafrai . . .	1	Do.
Gram imported into Boston, U. S. A. from Italy (Plarius)	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Gram imported into U. S. A. from Italy	1	Fairly resistant
Gram imported into U. S. A. from Sonora Mexico	1	Susceptible and killed by the disease
Gram imported into U. S. A. from East Mexico	1	Do.
Gram imported into U. S. A. from Italy		Do.
Pois Chiches 84084	1	Less susceptible than others when young though ultimately severely attacked
Pois Chiches 84086	1	Do.
Gram from Alexanderoply. . .	1	Do.
Gram from Australia . . .	1	Susceptible and killed by the disease
Gram types from Baghdad, Nos. 1, 3, 4, 6, 7, 8, 9, 13, 16, 17, 18 and 19	12	Do.
Gram from Bratislavia . . .	1	Do.
Gram from Bulgaria . . .	1	Less susceptible than others though ultimately severely attacked
Gram from Ceylon, samples 1—2 .	2	Susceptible and killed by the disease
Gram from Egypt, samples 1—5 .	5	Sample No. 3 less susceptible than others though ultimately severely attacked
Gram from Greece, samples 1—9 .	9	Sample called Greece mixture less susceptible than others though this was also severely attacked
Gram from Palestine, samples 1—4 .	4	Susceptible and killed by the disease
Gram from Russia, samples 1—4 .	4	Do.
Gram from Sodovo	1	Infection moderate to severe, produced some grains
Rumania, S_1, S_2 and S_3 . . .	3	On S_3 infection traces to severe, others killed
Portugal, S_1 and S_2	2	Killed by the disease
Compoinsonza	1	Do.

TABLE I—*concld.*

Types and collections	Number of samples	Nature of infection
Urozekbez, S_1 and S_2 . . .	2	Infection on S_1 moderate, and on S_2 moderate to severe. Both produced some grains
Malta	1	Killed by the disease
Candia, S_1 and S_2	2	Do.
Morocco, S_1, S_2, S_3 and samples 1-6 .	9	Infection on S_2 moderate to severe and produced some grains. S_1, S_3 and samples 1-6 were killed
Morocco Rabat	1	Killed by the disease
Cairo, S_1 and S_4	2	Do.
Tunisie, S_1-S_9	9	Do.
Addis Ababa S_1-S_3	3	Infection on S_1 severe, but produced some grains; S_3 totally killed
Nyasaland	1	Killed by the disease
Somaliland, S_1 and S_2	2	Do.
Rhodesia, S_1-S_3	3	Do.
Algeria, 2 samples and 418 . .	3	Do.
Libanizi	1	Do.
Persia, S_1, S_3, S_4, S_8, S_{10}, S_{11}, S_{12}, and S_{14}	8	Infection on S_3 and S_{11} moderate to severe and these two produced some grains, while the others were killed
U.S.A. 606 B, 606 C, 606 D, 607, 609 A, 609 B, 609 C, 610 A, 610 B, 613 A, 619 A, and one large seeded	12	Killed by the disease
Washington	1	Do.
Lima, S_1, S_2 and S_3	3	Do.
Versailles	1	Do.
Palestine S_5	1	Do.

C. RELATIVE RESISTANCE OF THE THREE SELECTED TYPES

(*i*) *Inoculations by spraying spore suspension*

The detailed observations (average of three years) on the relative infection of the three selected types (F 8, F 9 and F 10) when artificially inoculated by

spraying with a suspension of spores of the causal fungus are recorded in Table II.

It will be seen that not a single plant of F 8, F 9 or F 10 was killed by the disease, whereas all plants of Pb T 7 and Pb T 15 were killed. It was, however, observed that plants of F 8 got slight traces of infection. The lesions were faint and superficial and often bore no pycnidia. This slight infection did not cause injury.

As regards relative resistance, F 10 is the best, F 8 is intermediate and F 9 is rated third. It is estimated, however, that none of the three types can be regarded absolutely immune from the disease. These types ripened satisfactorily with well-developed pods filled with normal seeds. Moreover in the inoculation tests referred to above the most favourable and rigorous conditions for the development of the disease were provided artificially, which in nature can seldom be present.

TABLE II

Relative resistance of the three selected types of gram

Method of inoculation	Types of gram	Percentage of plants killed	Percentage of branches killed	Percentage of pods killed
1. Spraying spore suspension	F 8	0	0	0
	F 9	0	0	0
	F 10	0	0	0
	Pb T 7	100	All the plants killed	
	Pb T 15	100	All the plants killed	
2. Spreading blighted debris over the plants	F 8	0	0	0
	F 9	0	0	0
	F 10	0	0	0
	Pb T 7	100	..	..
	Pb T 15	100	..	..
3. Sowing seed mixed with blighted gram plant debris	F 8	0	0	0
	F 9	0	0	0
	F 10	0	0	0
	Pb T 7	100	All the plants killed	
	Pb T 15	100	All the plants killed	

(ii) *Inoculations by spreading blighted gram debris over the plants*

The results of inoculation experiments by spreading blighted gram plant debris on the three types F 8, F 9 and F 10 are also given in Table II. These are similar to those obtained when inoculations are done by spraying spore suspension from a pure culture of the fungus.

(iii) *Healthy seed mixed with blighted debris*

Experiments were conducted to see how far the disease could be transmitted by healthy seed mixed with blighted debris. The results of such experiments are given in Table II.

It is clear that when blighted debris is mixed with seed, infection appears in the seedlings and the extent of the infection is almost the same as when inoculations are done by spraying spore suspension or spreading blighted debris on the plants. All the plants of Pb T 7 and Pb T 15 were killed.

D. Further resistance tests with the three selected types

In order to test the resistance of the selected types at all stages of their growth and under different environmental conditions the following experiments were conducted. In all these experiments the selected types F 8, F 9 and F 10 were grown side by side with Pb types 7 and 15 unless otherwise stated.

(a) *Resistance at different stages of growth*

In this connection two experiments were conducted.

Experiment (i).—The five types, i.e. F 8, F 9, F 10, Pb T 7 and Pb T 15 were sown on 25 October 1936 in nine series of plots, and each series was inoculated at fortnightly intervals beginning from 1 December 1936 to 1 April 1937.

Experiment (ii).—The five types were sown in six series on different dates at fortnightly intervals beginning from 25 October 1936 to 10 January 1937, and all the series were simultaneously inoculated on 15 February 1937.

The results, which were recorded on 2 April 1937, showed that in both the experiments Pb types 7 and 15 caught severe infection and were totally killed, whereas F 8, F 9 and F 10 had only traces of infection and no harm was done to any part of the plant. The experiment was repeated in 1937-38 and similar results were obtained. It is, therefore, concluded that F 8 and F 10 are resistant to blight at all stages of their growth.

(b) *Resistance when manured with different fertilizers*

Six sets of plots were prepared and the following fertilizers were added :—

(1) Ammonium sulphate at 200 lb. per acre
(2) Superphosphate at 125 lb. per acre
(3) Potassium sulphate at 50 lb. per acre
(4) Complete (Superphosphate 72 lb., ammonium sulphate 144 lb. and potassuim sulphate 72 lb. per acre)
(5) Farmyard manure at 200 mds per acre
(6) Unmanured.

The five types were sown in the various plots on 28 October 1937. They were inoculated on 15 March 1938 and observations were recorded on 18 April 1938. The results were that in all the plots Pb types 7 and 15 were killed, whereas F 8, F 9 and F 10 resisted the disease.

(*c*) *Resistance under different amounts of irrigation and rainfall*

F 8 and Pb type 7 were sown on 28 October in two series of plots. In the first series the plots received 0, 1, 4, 6, 8 and 10 in. of irrigation up to 4 April 1938, when all the plots were inoculated. These plots were protected from rain by covering them with thick *sarkanda* screens, when rain was expected.

In the second series, which had to receive different amounts of natural precipitation only, five sets of plots were arranged. The first set received no rain, and the remaining ones received 1·1, 2·1, 3·3 and 5·4 in. of rain respectively up to the 4 April 1938. In this series also the plots, after they had received a certain amount of rain, were protected from further precipitation in the same manner as in the first series.

The results as recorded on 20 April 1938 showed that Pb T 7 was totally killed, and F 8 resisted the disease.

(*d*) *Resistance of the crop when grown in different localities*

F 8 along with Pb T 7 was grown at Lyallpur, Gurdaspur and Campbellpur in November 1936 and inoculated in March 1937. The results were that at all the three places Pb type 7 was totally killed and F 8 remained resistant to the disease.

The experiment was repeated in 1937-38 at Lyallpur, Campbellpur and Samli (Murree hills) and the results were similar.

(*e*) *Inoculation tests under adverse conditions for growth of gram*

In order to find out if F 8, F 9 and F 10 maintained their power of resistance, when grown under unfavourable conditions of light and aeration, two experiments were conducted for two years.

In one experiments the five types were sown on the 25 October 1936 and were allowed to grow normally up to 1 February 1937, when high *sarkanda* screens were erected around each plot close to the plants. Though the plots were kept open from above, yet the height of the screen always kept the plants under shade. These were inoculated on 10 March 1937.

In the other experiment the types were sown on 10 February and immediately after they germinated they were shaded similarly as above. These were also inoculated on 10 March 1937.

The experiment was repeated during the 1937-38 season on the same dates.

In both the series the plants produced soft and succulent shoots. Their stems and branches elongated abnormally, became slender and almost prostrated on the ground. The leaflets underwent a considerable reduction in size, and their colour became light green.

The results for both the years are summarized in Table III.

Table III shows that in both the series both the Pb types 7 and 15 caught severe infection and died. On the other hand, not a single plant of F 8, F 9 and F 10 was killed though, due to their extremely enfeebled state, they caught considerably more infection than under normal conditions.

TABLE III

Results of inoculation tests under adverse and normal light conditions (1936-37 and 1937-38)

Year	Gram types	Normal			Adverse		
		Percentage of plants killed by blight	Percentage of branches killed	Percentage of pods killed	Percentage of plants killed	Percentage of branches killed	Percentage of pods killed
1936-37 .	F 8	0	0	0	0	0	0
	F 9	0	0	0	0	0	0
	F 10	0	0	0	0	0	0
	Pb T 7	100	..	..	100	..	..
	Pb T 15	100	..	..	100	..	..
1937-38 .	F 8	0	0	0	0	0	0
	F 9	0	0	0	0	0	0
	F 10	0	0	0	0	0	0
	Pb T 7	100	..	..	100	..	..
	Pb T 15	100	..	..	100	..	..

From the experiments described under Section II B, C and D, it is quite evident that the three types Nos. 4732, 199 and 281, which are termed F 8, F 9 and F 10 respectively, are resistant to the blight disease at all stages of their growth and under different environmental conditions. They have also remained resistant whether inoculated artificially by a spore suspension, by spreading blighted gram plant debris on the plants or when raised from seed with which blighted debris was mixed. Even when these types were grown under unfavourable conditions of light and aeration, they showed a high degree of resistance to the disease. In all the inoculation experiments, not a single plant of any of these types was killed by the disease, whereas all the plants of the local selected types Pb 7 and 15 were destroyed by it.

As regards relative resistance, F 10 comes first, F 8 is second and F 9 is third.

E. Characters of the seed of the three resistant types

The seed of F 8 is yellow and has a rough surface. The seed resembles Pb 7, but its weight is about $1\frac{1}{2}$ times as great.

The seed of F 9 is dull white in colour, has a smooth surface and is of medium size. Its weight is about $1\frac{1}{2}$ times that of the usual type.

The seed of F 10 is black with a slightly rough surface. Its weight is $2\frac{1}{4}$ times that of the usual type.

F. Yield performance of the resistant types

About one ounce of seed of each of these three types, F 8, F 9, and F 10, among others was supplied by the Bureau of Plant Industry, Washington, U. S. A. They were grown at Campbellpur. These three types gave indication of high resistance to blight in the first year of trial in 1933 and single plant selections were made. The isolation of vigorous plants and those well adapted to the climate was continued every year. In the 1935-36 crop, enough seed of these types was raised to lay out experiments on field scale with a view to examining their yielding capacity. During the *rabi* (winter) season of 1936-37 the three resistant types, viz. F 8, F 9 and F 10, were grown at Campbellpur side by side with the Punjab gram types Nos. 7, 15, 4, 25 and local (a mixture of Punjab types 17 and 19) in regular plots each measuring 85 ft. 1 in. × 16 ft. (1/32 acre in area). There were eight replications of F 8 (the yellow-seeded variety) against seven each of the Punjab types 7 (yellow seeded), 15 (yellow seeded) and local (brown seeded). Only five replications of F 9 (white seeded) and three of F 10 (black seeded) could be arranged against five of Pb 4 (white seeded) and three of Pb 25 (black seeded) respectively. Sowing was done on 10, 11 and 12 October 1936.

In 1937-38 only F 8 was compared with Pb 7 and 15. The area of each plot was 1/60 acre (11 ft. × 66 ft.) and there were ten replications. Sowing was done on 18 and 19 October 1937.

The seed rate was calculated on the basis of the absolute weight of the seed of the various types in order to get a comparable crop of equal stand of each. Seeds of F 8, F 9 and F 10 are 1·5, 1·56 and 2·25 times respectively as heavy as those of Punjab type 7. The standard seed rate of Pb 7 is 16 seers (32 lb.) per acre. Therefore, the seed rate used was 24 srs. (48 lb.) for F 8, 25 srs. (50 lb.) for F 9 and 36 srs. for F 10 per acre.

Germination.—Good and uniform germination was obtained in all the plots except in those of F 10 which germinated irregularly even up to one month after sowing on account of the preponderance of hard seeds in it. The germination of F 8 took place about a couple of days later than that of Pb 7, and F 9 emerged almost at the same time as Pb 7.

Yield.—The yield data are given in Tables IV and V.

In 1936-37, all the Punjab types included in the field trials were totally wiped out by the blight disease and did not yield even a single grain. F 8 on the other hand yielded 1165 lb. per acre.

In 1937-38, F 8 yielded on an average 1140 lb. per acre and Pb 7 and 15, 420 lb. and 108 lb. per acre respectively. From these figures it is clear that under Campbellpur conditions F 8 is far superior to Pb 7 or Pb 15.

TABLE IV

Yield of grain (lb.) of F 8, F 9, F 10, Pb 7 and 15 during 1936-37

(Area of each plot 1/32 acre)

Serial No.	F 8	F 9	F 10	Pb 7	Pb 15
1	51	8	10	0	0
2	32	4	6	0	0
3	40	4	14	0	0
4	15·5	3			
5	32·5	14			
6	42·0				
7	41·0				
8	37·0				
Average yield per plot in lb.	36·4	6·6	10	0	0
Average yield per acre in lb.	1,165	211	320	0	0

G. SELECTION OF F 8 FOR DISTRIBUTION TO FARMERS

The seed of F 8, being similar to the premier Punjab types (Pb 7 and 15 which are already being recommended by the Agricultural Department and are actually grown by the farmers in the province, is liked by the farmer. This type, as the above experiments show, has proved satisfactory as regards yield, and thus fulfills one of the crucial tests usually applied to determine the value of newly evolved strains from the viewpoint of the farmers, i.e. enhanced return per acre. The most significant and priceless asset of the type is its ability to withstand the destructive blight disease, on account of the prevalence of which the cultivation of gram in the north and submontane districts of the Punjab has become problematical. The poor farmer of the greater part of this tract particularly in the north Punjab has been threatened with the loss of a crop which is his only means of subsistence. Gram is the life and soul of the people, and blight has been a calamitous visitant and a great menace for long in this part of the country. The selection of the resistant strain is a priceless boon to them and the surrounding area, including the North-West

Frontier Province, where also the disease has taken a strong hold. Of the three resistant types, F 8 has been selected as the most suitable for introduction into the husbandry of the province as a new production to replace the local seed and combat the blight disease.

TABLE V

Yield of grain (lb.) of F 8, Pb 7 and Pb 15 during 1937-38

(Area of each plot 1/60 acre)

Replications	F 8	Pb 7	Pb 15
I	22	4·0	2·5
II	18	10·5	2·0
III	21	6·5	2·2
IV	16	9·0	4·0
V	19	6·0	0·5
VI	20	6·0	0·5
VII	21	5·5	0·5
VIII	12·5	6·0	1·5
IX	20·0	8·5	2·0
X	21·0	8·0	3·0
Average yield per plot in lb. . . .	19·0	7·0	1·8
Average yield per acre in lb. . . .	1,140	420	108

In 1938, about 60 mds (1 maund $=82\cdot3$ lb.) seed of this type was produced. The whole of it was sown at the Agricultural Farms, Risalewala (Lyallpur), Sargodha, and Campbellpur and 1235 mds of seed became available in 1939. This is being further multiplied under strict supervision, and it is expected that in 1940 about 25,000 mds of seed of this type will be in hand for supply to farmers and thus it will be possible to replace the local seed by F 8 in all the blight-affected areas of the province in two or three years.

III. SUMMARY

1. Three hundred and ninety-two types and collections of gram obtained from different places in India and foreign countries have been tested as regards their relative resistance to the blight disease of gram (*Mycosphaerella rabiei*=*Ascochyta rabiei*).

2. All the Indian types have been found susceptible to the disease and of the foreign types Pois Chiches 4732, No. 199 and No. 281, which are here called F 8, F 9, and F 10 respectively, showed high resistance to the disease.

3. The three types F 8, F 9, and F 10 have remained resistant under different environmental conditions.

4. Of the three resistant types, F 8 has given the best yield. This type also possesses other desirable characters.

5. F 8 has been selected for distribution to farmers in the blight-affected areas of the province. Its seed is now being multiplied, and it is expected that in 1940 about 25,000 mds of seed of this type will be available.

The authors wish to record their thanks to all the scientific workers in India and abroad, who very kindly supplied the seeds of different varieties of gram for this investigation.

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BIOLOGY AND CONTROL OF WOOLLY APHIS *ERIOSOMA LANIGERUM* HAUSM (APHIDIDAE : RHYNCHOTA) IN THE PUNJAB

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I. Introduction

Woolly aphis (or American blight) is a native of America [Greenslade, 1936]. It was noticed in the Punjab for the first time in 1909 in the Simla district on young apple plants which had been imported from England [Misra, 1920]. The work on its biology and control was taken up in the Kulu Valley (Punjab) in 1934 and the results of these investigations are presented in this paper.

II. Distribution

Woolly aphis is confined to the hilly tracts of the Punjab and has so far been reported from the following localities :—Simla, Mashobra, Kotgarh, Kotkhai, Solan, Kasauli, Jubbal State, and Koti State in the Simla district and Bajaura, Kulu, Bandrole, Niramiti, Raison, Shirir, Katrain, Dobi, Naggar, Karjan and Manali in the Kulu Valley.

III. Food-plants

Greenslade [1936] states that ' the chief hosts of woolly aphis are apple and American elm.' He further maintains that 'it has also been recorded from the following plants ' but ' some of these records may be due to faulty identification of the aphis '.—

Crataegus crus-galli

C. punctata

C. oxyacantha

C. cuneata

Pyrus toringo [*P.* (*Malus*) *sieboldii*]

P. (*Sorbus*) *americana*

P. americana var. *decora* (*P. sitchensis*)

P. malus var. *paradisiaca* (*P. malus* var. *pumila* or *P. pumila paradisiaca*

Cotoneaster horizontalis

C. acutifolia

Pyrus (*Malus*) *scheideckeri*

P. aucuparia

Cydonia vulgaris (*Pyrus cydonia*)

Pyrus communis

Salix sp.

Syringa vulgaris

In the Punjab woolly aphis is confined to apple and crab apple (*Pyrus baccata*, vernacular name *pala*). Efforts to find it on other plants as mentioned by Greenslade have been in progress since 1934, but up to this time the pest has not been found on any one of them. The varieties of elm—*Ulmus americana* and *U. campestris*—which are known to be its alternative host-plants in America are not found in the Punjab and a search for its presence on the varieties, *U. villichiana* and *U. lavigata*, found in the Kulu Valley yielded negative results.

A few plants of *Ulmus campestris* were obtained in 1936 through the courtesy of the Divisional Forest Officer, Murree. They were planted in a wire-gauze cage (measuring 10 ft. × 5 ft. × 5 ft.) which had a few heavily infested crab apple plants growing in it since December 1935. These elm plants were artificially inoculated with woolly aphis first in March 1936 and then regularly afterwards up to November 1937. The pest has never succeeded in establishing itself on *U. campestris* and it always perished in three to four days after inoculation. At the time of writing both the plants are still growing in the cage and the crab apple is seriously suffering, while *U. campestris* is absolutely free from woolly aphis.

IV. Life-history

Viviposition.—In America woolly aphis produces sexual forms before winter which lay eggs on elm bark [Patch, 1912]. These eggs hatch in spring when infestation starts. In the Punjab, on the other hand, the pest neither produces any sexual forms nor it migrates to the elm tree ; it viviposits throughout the year on apple. Moreover, in spite of our very careful and diligent searches extending over six years (1934-40), we have never found a male woolly aphis. Thus it is concluded that the woolly aphis in the Punjab does not produce any males, its reproduction being parthenogenetic and the parthenogenetically produced progeny consisting of females only.

Rate of reproduction.—The number of young produced by a female in her life-time depends upon the season : during November-February a female produces 48-87, and during March-November 30-116 young ones. The young ones are produced by instalments, a female resting for 4-24 hours during March-September and for eight hours to a week during November-February, after every parturition. The number of young produced by a female daily varies from one to six, the largest number of them being produced during July-August

and the smallest during December-February. A female takes 7-12 minutes to give birth to one nymph.

TABLE 1

Viviposition record of woolly aphis on apple at Kulu

(Number of observations made 110, but for brevity only 15 are mentioned)

Number	Female sleeved		Number of young produced		Total number of young produced by one female
	From	To	Daily	Weekly	
1	11 Mar.	1 May	1—5	..	30
2	,,	,,	1—5	..	112
3	20 May	28 June	1—5	..	50
4	,,	,,	1—5	..	73
5	2 Aug.	8 Oct.	1—6	..	116
6	,,	,,	1—6	..	74
7	,,	,,	1—6	..	108
8	,,	,,	1—6	..	85
9	6 Oct.	21 Nov.	1—4	..	91
10	,,	,,	1—4	..	71
11	,,	,,	1—4	..	62
12	15 Nov.	27 April	..	1—2	87
13	,,	,,	..	1—2	48
14	,,	,,	..	1—2	70
15	,,	,,	..	1—2	60

A nymph is born with the tip of its abdomen first. A newly born nymph becomes active within 15 minutes of its birth. The nymphs are gregarious and a large number of them fix themselves together on the plant either near about their mothers or away from them, the cotton wool appearing over their bodies 24 hours after fixation.

Nymphal instars.—There are four nymphal instars. The duration of each nymphal instar varies according to the season (Table II).

TABLE II

Duration of nymphal instars of woolly aphis during different months at Kulu

Serial No.	Born on or between	I instar Total duration (days) Min.	I instar Max.	I instar Av.	II instar Total duration (days) Min.	II instar Max.	II instar Av.	III instar Total duration (days) Min.	III instar Max.	III instar Av.	IV instar Total duration (days) Min.	IV instar Max.	IV instar Av.	Adults emerged between	Total duration of nymphal instar (days) Min.	Max.	Av.
1	7-9 Jan.	31	32	31·5	18	18	18	10	10	10	7	7	7	14-15 Mar.	66	67	66·5
2	2-5 Feb.	19	21	20	9	9	9	8	8	8	4	4	4	14-18 Mar.	40	42	41
3	12-24 Mar.	9	17	13	5	10	7·5	4	8	6	2	4	3	13-22 April	20	39	29·5
4	3-10 April	8	9	8·5	6	6	6	3	3	3	2	2	2	22-30 April	19	20	19·5
5	8 May	4	5	4·5	2	3	2·5	1	3	2·0	1	2	1·5	16-21 May	8	13	10·5
6	1 June	4	5	4·5	3	4	3·5	3	3	3	1	2	1·5	12-15 June	11	14	12·5
7	1-5 July	5	7	6	4	5	4·5	3	4	3·5	3	3	3	16-24 July	15	19	17
8	8-17 Aug.	10	12	11	8	10	9	7	9	8·5	6	8	7	8-25 Sept.	31	39	35
9	3-7 Sept.	12	13	12·5	10	11	10·5	9	9	9	4	7	5·5	8-17 Oct.	35	40	37·5
10	1-3 Oct.	12	14	13	8	10	9	7	9	8	5	7	6	2-12 Nov.	32	40	36·0
11	2-3 Nov.	14	16	15	10	12	11	8	10	9	6	8	7	10-18 Dec.	38	46	42
12	5-8 Dec.	40	43	41·5	30	30	30	12	12	12	8	8	8	7 Mar.	90	93	91·5

V. Seasonal history

The seasonal-history of woolly aphis was studied at Raison and Kulu.

Raison (*height above sea level 4,500 ft.*).—The pest becomes active in March when the overwintered females start viviposition, while the overwintered nymphs reach maturity in the first week of March when they also start viviposition. The pest multiplies rapidly in summer both on the aerial parts and the roots of the infested plants. In May partial migration takes place from the roots to the aerial parts of the attacked plants. The winged forms, which begin to appear in July, reach their maximum abundance in September. Thus during August-September majority of the nymphs develop into winged females although wingless females are also produced during this period. The winged forms die off in October. The pest is most active (and destructive) during March-September. It multiplies at a reduced pace during October-December, both on the aerial parts and roots of the attacked plant. During December-February its multiplication slows down very considerably. In December there is a partial migration from the aerial parts to the roots of the infested plants.

Kulu (*height above sea level 4,000 ft.*).—At Kulu there is no migration either in summer or in winter from aerial parts to the roots and *vice versa* of an infested plant. Otherwise, the behaviour of the pest is identical with that at Raison.

VI. Migration from aerial parts of an infested plant to its roots and *vice versa*

At Raison migration from the aerial parts to the roots of an infested plant takes place during the period from mid-December to mid-January, the nymphs migrating only during the hotter part of the day. The stem of the infested plant gets covered with the white wax-covered bodies of the migrating individuals, with the result that it looks white from a distance. Their migration is, however, only a partial migration, because, at its close a very large number of the nymphs (majority of them full-grown) and a few females are found to spend the winter on the aerial parts of the infested plant.

Return migration of the pest from the roots to the aerial parts of an apple plant takes place in summer at Raison and continues throughout May, the migration being partial, for the nymphs and females of the pest remain on the roots of each one of the infested plants right through the summer season. Thus at Raison woolly aphis remains active, both on the roots and the aerial parts of an infested plant, throughout the year. At Kulu proper, on the other hand, there is no migration whatsoever, the pest remaining present on the aerial parts and roots of the attacked plant throughout the year.

VII. Dispersal

(1) The winged forms appear during July-October in the Kulu Valley. They fly to other apple plants and start new colonies on them.

(2) According to Greenslade [1936] nymphs are blown from tree to tree in loose masses of wool. We have observed the same phenomenon in the Punjab also.

(3) We have also observed that newly born nymphs are responsible for infesting healthy plants in an orchard. These nymphs fall off ' or are blown off the tree and walk to the next tree ' [Greenslade, 1936]. We have found the young nymphs to be capable of crawling over a distance of 20 ft. on the ground to reach another plant.

Dispersal of the pest in the manner described under 2 and 3 is at its maximum during July-September at Kulu.

VIII. Damage

Greenslade [1936] has described succinctly several types of damage by this pest. Our experience is that : (1) fruit from a heavily attacked plant is of poor quality, being undersized, malformed and insipid in taste ; (2) damage to the aerial parts of a grown-up tree is more pronounced and serious than to roots, for the entire stem and most of the branches get covered with galls, this condition affecting the vitality of the plant adversely ; (3) roots near the surface of the soil are generally attacked and it is only in rare cases that the pest may go down as deep as 4 ft. In any case the damage to roots is not serious ; (4) Young nursery plants usually succumb to the attack of this pest.

IX. Insect predators

Greenslade [1936] gives a long list of insects which prey upon woolly aphis in different parts of the world. Some of these predators, e.g. *Syrphus balteatus* De G., *Adalia bipunctata* L., *Coccinella septempunctata* L., etc. are also found in the Punjab, but they have not so far been found to prey upon woolly aphis in the Kulu Valley and Simla Hills where it is preyed upon by the following predators :—

i. *Ballia eucharis* Muls.
ii. *Coleophora sauzeti* Muls.
iii. *Chilomenes bijugans infernalis* Muls.
iv. *Syrphus confrater* Weid.
v. *Coniocompsa indica* Withycombe.
vi. *Ancylopteryx punctata* Hag.

A brief account of each one of these predators is given below :—

(i) *Ballia eucharis* Muls. (Fig. 1) (Coccinellidae : Coleoptera).—This beetle is about 8 mm. long and about 7 mm. broad. It is dirty yellow in colour and each one of its elytra is ornamented with four black spots which are arranged as shown in the figure.

It is present on the plants infested with woolly aphis during summer only. It is never abundant and, as such, does not exercise any check on the pest.

(ii) *Coleophora sauzeti* Muls. (Fig. 2) (Coccinellidae : Coleoptera).—This beetle is about 4 mm. long and about 3 mm. broad. It is dirty yellowish in colour. Its pronotum is ornamented with a saddle-shaped black mark and each of its elytra is ornamented with one longitudinal stripe and four black dots as shown in the figure.

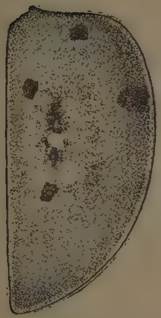

FIG. 1. Elytra of *Ballia eucharis*

FIG. 2. Elytra of *Coleophora sauzeti*

It is present among woolly aphis colonies during August-September. Like *B. eucharis* Muls., it also does not exercise any check on the pest.

(iii) *Chilomenes bijugans infernalis* Muls. (Fig. 3) (Coccinellidae: Coleoptera).—This beetle is 5 mm. long and 4 mm. broad. It is shining dark brown in colour with two large, oblong and two small, round light blood-red spots on elytra as shown in the figure.

FIG. 3. Adult of *Chilomenes bijugans infernalis* Muls. ($\times 8$)

FIG. 4. Adult of *Syrphus confrater* Wd. ($\times 3$)

It is active from March to November, but during December-February it hibernates both as pupa and adult. During spring it completes its life-cycle in 60 days as follows: egg stage, not known (but eggs collected from fields hatched in two to three days); larval stage 40; pupal stage 15 days.

This beetle is most common during May-July, when it exercises a definite check over woolly aphis. It is parasitized by *Tetrastichus* sp. (Eulophidae: banded Hymenoptera) which is not yet identified to species.

(iv) *Syrphus confrater* Wd. (Fig. 4) (Syrphidae: Diptera).—The adult is 8-11 mm. long. Dorsum of its thorax is 'steely aeneous' while the first segment of its abdomen is black and abdominal segments three to four with yellow and black transverse bands as shown in the figure.

This is a very common syrphid in the Kulu Valley which hibernates as a pupa. It is abundant specially during the period from June to September-October. Its life-cycle is completed in 26-30 days. It keeps the pest in check, particularly during July-September.

(v) *Coniocompsa indica* Withycombe (Coniopterygidae : Neuroptera).—This predator is of very rare occurrence in the Punjab, and as such does not exercise any check on woolly aphis.

(vi) *Ancylopteryx punctata* Hag. (Fig. 5) (Chrysopidae : Neuroptera).—Adult measures 8 mm. in length and is 25 mm. in the wing expanse. Its body is shining light green and is furnished with a creamy white longitudinal mid-dorsal line. Antennae are yellowish and the wings hyaline with veins light green.

FIG. 5. Adult of *Ancylopteryx punctata* (×3)

This is a common predator in the Kulu Valley. It is active during April-November but during December-March it hibernates as pupa. Its life-cycle is completed in three to four weeks. It is most abundant during April-June and September when it exercises a definite check on the pest.

X. CONTROL MEASURES

INSECTICIDAL CONTROL

a. Control of aerial forms

(i) Greenslade [1936] recommends spraying the infested plants with : (1) 20 per cent of tar distillates, or (2) 4 per cent petroleum sprays in the dormant period and by 1 per cent summer oil sprays with or without the addition of nicotine in the summer. Some workers have also recommended kerosene oil emulsion against this pest. These insecticides together with those commonly employed in the Punjab [Rahman, 1940] were tried and discarded in favour of rosin soap. This soap was prepared by us as follows :—

Mohwa (*Bassia latifolia*) oil	21 seers
Caustic soda	7 seers
Rosin	32 seers
Water	25 seers

Three seers of caustic soda were dissolved in 10 sr of water and 21 sr of *mohwa* oil were added to the solution which was stirred well. It was left overnight to form soap.

The remaining 4 sr of caustic soda were dissolved in the remaining 15 sr of water. The 32 sr of rosin were powdered and added to this solution. The soda-rosin mixture was boiled until rosin was completely dissolved and the mixture assumed a dark brown colour. Soap (formed by *mohwa* oil and caustic soda) was cut up into thin slices and added to this dark brown caustic-rosin mixture and boiled until a homogeneous mixture was obtained. This mixture was allowed to cool and set.

TABLE III

Effective concentration of rosin soap for woolly aphis

(Number of experiments carried out 20, but for brevity only 5 are given below)

Quantity (in chhataks) dissolved in 20 seers of water	Number of living aphids (all stages) per shoot before spraying	Number of dead aphids (all stages) per shoot after spraying	Per cent mortality
3	325	95	29
4	425	192	45
5	614	516	84
6	521	495	95
7	365	365	100

It is seen from Table III that rosin soap when used at the rate of 7 ch. in 20 sr of water gave cent per cent mortality.

(ii) *Smudging*.—Fumes of creosote and sanitary fluid were tried as smudges during September-October in fine weather. These chemicals were poured on smouldering heap of leaves placed under the infested limb of a plant where they produced a dense column of smoke. The results are presented in Table IV.

TABLE IV

Efficiency of creosote and sanitary fluid as smudges against wooly aphis

(Exposure for two hours)

Chemical	Quantity (in oz.) per tree	Number of living aphids per colony before smudging	Number of dead aphids per colony after smudging	Per cent mortality
Creosote .	1	232	*Nil*	*Nil*
	2	167	..	..
	3	135	..	..
	4	212	..	..
	6	67	..	..
	8	335	..	..
Sanitary fluid	1	212	..	..
	2	198	..	..
	3	115	..	..
	4	174	..	..
	6	215	..	..
	8	235	..	..

It will be observed from Table IV that creosote and sanitary fluid as smudges are entirely useless against woolly aphis.

b. Control of root-infesting forms

Insecticides tried to control the root-infesting forms are discussed below :—

(i) *Paradicholorobenzene*.—It proved very effective against the root forms : it also killed the migrating individuals at Raison during December-January and in May. The poison was applied in a 4-in. deep trench covered with earth. The results are presented in Table V.

(ii) *Calcium cyanide*.—It also proved very effective, but was neither so lasting nor so cheap as P. D. B. Besides, it had no effect on the migrating forms.

The results are presented in Table VI.

TABLE V

Efficiency of paradicholorobenzene (P. D. B.) against woolly aphis

(P. D. B. sells at 0-4-3 per oz.)

(Number of experiments carried out 172, but for brevity only 18 are given below)

Date of application	Quantity applied (in oz.) per tree	Radius of the ring (in ft.)	Age of the tree (in years)	Per cent mortality	Remained effective for
17 Dec. . .	½	5	12	75	1½ months
	1	5	12	100	,,
	2	5	12	100	,,
	3	5	12	100	,,
21 Jan. . .	¼	2	3	82	,,
	⅓	2	3	100	,,
	½	2	3	100	,,
26 Jan. . .	1	5	12	100	,,
	2	5	12	100	,,
18 Feb. . .	2	5	10	100	,,
	4	10	25	100	,,
17 May . .	2	5	12—15	100	3 weeks
	2	5	12—15	100	,,
	4	10	26	100	,,
	4	10	26	100	,,
	1	5	5	100	,,
	1	5	5	100	,,
	1	5	5	100	,,

TABLE VI

Efficiency of calcium cyanide against woolly aphis

(Calcium cyanide sells at Rs. 1-12 per lb.)

(Number of experiments carried out 475, but for brevity only 7 are given below)

Date of application	Quantity applied (in oz.) per tree	Radius of the ring (in ft.)	Age of the tree (in years)	Per cent mortality	Remained effective for
21 Jan. . .	¼	2	3	90	One week
	⅓	2	3	95	,,
	1	5	12	95	,,
	2	5	12	100	,,
18 Feb. . .	2	5	8—12	100	,,
	4	10	25	100	,,
17 May . .	2	5	12	100	,,

Contrary to the observations of Reppert, Schoene, and Underhill [Greenslade, 1936], calcium cyanide did not cause any damage to the roots of the trees under experiments.

(iii) *Carbon bisulphide.*—This was applied with the 'soil injector'. It gave cent per cent mortality round about the place of injection (duration of effectiveness =3-4 days), but aphids away from the place of injection were not at all affected by it. It was not so effective as P. D. B. or calcium cyanide.

(iv) *Sanitary fluid.*—It proved as effective as P. D. B. and in the soil its effect lasted for about three weeks. It killed 100 per cent of the root forms, but produced no harmful effects on the roots. It is, however, very costly and can only be applied in localities where plants are regularly irrigated. The results are presented in Table VII.

TABLE VII

Efficiency of sanitary fluid against woolly aphis

(Sanitary fluid sells at Re. 1 to Rs. 2 per gallon)

(Number of experiments carried out 11, but for brevity only 5 are mentioned)

Date of application	Quantity applied (in gallons) per tree	Radius of the ring (in feet)	Age of the trees (in years)	Per cent mortality	Remained effective for
17 Dec. . .	$\frac{1}{4}$	5	12	85	two weeks
	$\frac{1}{2}$	5	12	85	,,
	1	5	12	95	,,
17 May . .	$\frac{1}{2}$	5	12	81	One week
	1	5	12	98	,,

(v) *Powdered naphthalene.*—This was applied like P. D. B. It gave very low mortality indeed and did not damage the roots of the treated trees. The results are presented in Table VIII.

TABLE VIII

Efficiency of powdered naphthalene against woolly aphis

(Number of experiments carried out 20, but for brevity only 4 are mentioned)

Date of application	Quantity applied (in lb.) per tree	Radius of the ring (in ft.)	Age of the tree in years	Per cent mortality	Remarks
15 Nov. . .	1	5	10	3	Mortality was observed only in cases when naphthalene powder was quite close to the colonies.
	2	5	10	7—8	
	3	5	10	15	
	4	5	10	17—18	

(vi) *Tobacco dust*.—Contrary to Greenslade's [1936] assertion, tobacco dust did not prove useful at all. When the roots were opened up after the treatment, it was found that the dust did not affect the root forms in any way. Migration of root forms from the treated trees took place as usual.

TABLE IX

Efficiency of tobacco dust against woolly aphis

(Number of experiments carried out 19, but for brevity only 7 are given below)

Date of application	Quantity applied (in sr) per tree	Radius of the ring (in ft.)	Age of the trees in years	Per cent mortality
26 Jan.	¼	5	3	*Nil*
	½	5	3	*Nil*
	1	5	12	*Nil*
	2	5	12	*Nil*
	3	5	12	*Nil*
17 May	4	5	12	*Nil*
	6	5	12	*Nil*

ACKNOWLEDGEMENTS

This line of work was suggested by M. Afzal Husain, Entomologist to Government, Punjab, Lyallpur and to him we are grateful for helpful suggestions until his appointment as Vice-Chancellor of the Punjab University in 1938.

XII. SUMMARY

Woolly aphis (*Eriosoma lanigerum* Haus.) is a native of America. It was noticed in the Punjab for the first time in 1909 in the Simla district on young apple plants which had been imported from England. It is found in the Simla Hills and the Kulu Valley exclusively on apple.

Reproduction in this pest takes place by parthenogenesis, the progeny consisting of females only. The nymphs reach maturity in 8-19 days during May-July. The number of young produced by a female depends upon the season, but the largest number of them are produced during July-August.

Woolly aphis attacks both aerial parts and the roots of the apple plant. Migration of the aerial forms to the roots and *vice versa* depends upon the altitude of the locality; at Kulu there is no migration, but at Raison there is a partial migration during December-January and in May. The winged forms appear in July-October when they fly to healthy plants and start new colonies. The pest is also spread through the agency of wind.

The attacked plant yields fruit of poor quality.

Of the insect predators of woolly aphis discussed in this paper *Chilomenes bijugans infernalis* Muls., *Syrphus confrater* Wd. and *Ancylopteryx punctata* Hag. exercise definite check on it.

The aerial forms of the pest can be effectively controlled by spraying them with rosin soap, while the root forms are best dealt with by paradicholorobenzene.

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STUDIES ON THE PERIODIC PARTIAL FAILURES OF PUNJAB-AMERICAN COTTONS IN THE PUNJAB*

III. THE UPTAKE AND THE DISTRIBUTION OF MINERALS IN THE COTTON PLANT

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INTRODUCTION

THE symptoms exhibited by the American cotton plants suffering from the physiological disease known as *tirak* during the failure years resembled the symptoms of plants that suffer from some deficiency disease. The yellowing and reddening of the leaves and the immaturity of seeds are generally indicative of deficiency of some important mineral, like potassium or nitrogen. Such symptoms of deficiency disease are known to occur in many crop plants. It was thought probable that the American cotton plants in the Punjab also suffered from some disturbance in their mineral or nitrogen metabolism and developed the symptoms of the disease commonly designated as *tirak*. A study of the uptake of different minerals and nitrogen and their relative distribution, stage by stage, in the different parts of the normal 4F American cotton plant was, therefore, undertaken with a view to making a similar study later of the diseased plants, so that the nature and the time of any such disturbance in the mineral nutrition of the latter could be determined. The present paper relates only to the mineral uptake and its distribution in normal plants as it is first necessary to study the normal trends in the mineral nutrition of the plant to differentiate the abnormal features that may be present in the diseased condition. For the sake of completeness and comparison, the *desi* plants, which are generally not found to suffer from such a disease, are also included in this study. It may be mentioned here in passing that the mineral composition and its uptake stage by stage by the American and *desi* plants have not been determined in the Punjab, where cotton is the most important crop, and therefore this appeared to be an additional reason for undertaking the investigation in its present form.

The mineral composition of the cotton plant at one stage or the other has been determined by workers abroad [Hutchinson and Patterson, 1892; Fraps, 1919; McHargue, 1926]. White [1914-1915] found that maximum amounts of nitrogen, potassium and phosphorus were absorbed by the cotton plant at the blooming stage. Similar findings have also been reported by

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Kundrin [1929], Holley, Pickett and Dulin [1931], Armstrong and Albert [1931] and by Murphy [1936].

Material and methods

The 4F American and Mollisoni *desi* plants were grown* in alternate rows to minimize the effects of soil heterogeneity in Square 10 of the Lyallpur Agricultural Farm. The soil was a sandy loam with 63·9 per cent of sand. 19·88 per cent of silt, 14·2 per cent of clay and 3 per cent of carbonates in the upper 3 feet. The soil reaction was at *p*H 8·1 and the total water-soluble solids were about 920 p.p.m. in the same layers. The land was fallow during the previous year. The sowing was done on 14 May 1935 and the plants were finally thinned on 9 July to $1\frac{1}{2}$ ft. between the plants keeping one plant per hole. The distance between the rows was kept at 3 ft. In the case of the *desi* variety, the spacing between the plants was 1 ft. These spacings are the normal spacings adopted for the two varieties in the Punjab.

The plants were labelled at random for sampling. The samples were taken every fortnight. In the early stages, 30-40 plants had to be sampled, but this was reduced later to 10 plants. The samples were collected in the morning with roots up to a depth of $2\frac{1}{2}$ ft. The fresh weights were recorded immediately after removal. Adhering particles of sand were removed and the different parts were chopped up into bits and a representative sample of each part was taken for determination of moisture. A second representative sample was dried in an electric oven at 40°-45°C. The samples after drying were powdered and kept in stoppered bottles for chemical analysis.

Standard A. O. A. C. methods of analysis were employed for determination of silica-free ash, nitrogen, potash, phosphoric acid, lime, magnesia, aluminium and iron. Sulphur and chlorine were determined gravimetrically and volumetrically respectively, care being taken to include sulphur and chlorine present in the organic form.

Sodium was determined as sodium-magnesium-urenyl acetate after removing all interfering ions. Manganese was determined by sodium bismuthate method, copper by potassium ethyl xanthate method and zinc by potassium ferrocyanide nepholometric method. 10-25 gm. of air-dried material were taken for ashing and subsequent analysis. For copper, zinc and manganese, 50 gm. of material had to be taken on account of very small quantities of these elements present in the plant. The analysis was made in duplicate.

Presentation of data

The results of analyses are discussed in two sections. Section 1 deals with the mineral composition of American and *desi* cotton plants at maturity. The uptake and distribution of different minerals in the whole plant and in its different parts, of each variety, at different stages of growth, are dealt with in section 2. The study of distribution of dry matter and moisture is also included in the latter. All results are expressed graphically.

The results of mineral and nitrogen contents were calculated and studied in more ways than one. The results were calculated per whole-plant basis and per each part of the plant, per 100 gm. of the whole plant and per 100 gm.

*No effect on the growth of American varieties is noticeable either when they are grown mixed with *desi* cottons or as unmixed crop.

of each part of the plant, per 100 gm. of ash of the whole plant and per 100 gm. of ash of each part of the plant. The quantity of each mineral at different stages expressed as percentage of the total quantity absorbed by the whole plant was determined. The percentage distribution of each mineral in the different parts of the plant at different stages of growth was also determined. The relative rate of uptake of each mineral was arrived at from the formula $R=(\log M_2—\log M_1)$ where M_1 and M_2 are the quantities of minerals at two consecutive stages of growth [Gregory, 1926].

Statistical analysis of the data

The differences found between the various mineral contents of the American and *desi* plants could not be put to a statistical test as the analysis was not carried out on replicates at each stage. The Fishers ' t ' test could not therefore be applied. The analytical data given here form a time series, and consistent differences in some minerals in the two varieties at all stages of growth are found. Though the ' t ' test is not strictly valid in such cases, it is applied neglecting the effect of time, and significant differences are found between certain minerals in the two varieties. So, whenever a mention is made in the text of a particular difference as statistically significant, it is implied that the ' t ' test is applied to such a time series.

§ 1. *Mineral composition of the American and* desi *cotton plants*

The quantities of different minerals and nitrogen found in two varieties of the cotton plant are given in Table I per whole-plant basis and per 100 gm. of the whole plant. The differences in the quantities of minerals seen in the two plants, per whole-plant basis, are mainly due to the differences in their dry weights. The mineral contents of the two varieties at maturity per 100 gm. dry weight are nearly the same except in two cases. The American plant contains more potash and less lime and sulphates than the *desi* plant. Lime, potash, sulphates and nitrogen are found in largest amounts in each variety, while the remaining minerals are found in small quantities.

The above results of mineral contents of the cotton plants have been verified by analysing the cotton plants in succeeding seasons. It is found that there are small differences in the mineral contents of plant parts of a variety grown in different fields, but the trends in the uptake of a mineral at different stages of growth are found to be the same.

Table I

Mineral and nitrogen contents of American (24 December 1935) and desi *(26 November 1935) plants*

Variety	Dry wt	Silica-free ash	N_2	K_2O	CaO	MgO	$Al_2O_3+Fe_2O_3$	P_2O_5	SO_4	Cl_2
				Gm. per plant						
4F American	864·7	69·47	14·52	17·84	19·37	3·79	0·49	3·02	12·95	2·72
Mollisoni *desi*	552·1	45·82	9·26	9·66	13·10	2·78	0·37	1·80	9·13	2·07
				Gm. per 100 gm. of the whole plant						
4F American	100	8·04	1·68	2·07	2·24	0·44	0·06	0·35	1·50	0·32
Mollisoni *desi*	100	8·30	1·68	1·75	2·36	0·51	0·07	0·33	1·66	0·38

Quantities of minerals removed from the soil by a cotton crop

From the number of cotton plants per acre a fair idea can be obtained regarding the total quantity of each mineral and nitrogen absorbed by a cotton crop from the soil. It is also possible to calculate the quantity of each mineral lost from the soil as a result of cropping for cotton, as that is the quantity which enters the seed cotton and the stems. The roots and the leaves generally remain in the soil and the minerals that are present in them are therefore returned back to the soil. The total quantities of different minerals and nitrogen absorbed by the cotton crops of the two varieties are given in Table II. A crop of American cotton of a stand of 9,000 plants per acre absorbs 100 lb. of potash and 75 lb. of lime more than a *desi* crop of 13,000 plants per acre. The soil gets depleted of 177 lb. of nitrogen, 190 lb. of potash and 40 lb. of phosphoric acid per acre when a crop of Americans is harvested, and of 192 lb. of nitrogen, 170 lb. of potash and 41 lb. of phosphoric acid when a crop of *desi* is harvested.

TABLE II

Quantities of different minerals and nitrogen in lb. absorbed and lost from the soil per acre (when yield of seed cotton is 15 mds. per acre)

Mineral	Total quantities absorbed		Total quantities lost	
	American	*Desi*	American	*Desi*
Nitrogen	288	283	177	192
P_2O_5	60	59	40	41
K_2O	353	250	190	177
CaO	384	308	90	113
MgO	75	85	42	43
SO_4	256	229	66	75
Cl_2	54	54	32	37
$Al_2O_3 + Fe_2O_3$	10	11	3	6

The losses of minerals and nitrogen from the soil in both cases are nearly equal. The loss of minerals and nitrogen to the soil will vary according to the stand, the yields of seed cotton per acre and properties of the soil where each crop is sown.

Mineral composition of different parts of the cotton plant

The quantities of minerals and nitrogen in different parts of the plant of the two varieties are given in Table III per plant basis and per 100 gm. of each part of the plant. The ash constituents are found in maximum amounts in the leaves of the two plants. This is due to the presence in leaves of largest

amounts of lime and sulphur, which are required in small amounts for the formation of bolls, as judged from the amounts found in them. Nitrogen contents of the bolls and leaves are nearly the same in both the varieties. The leaves of the *desi* plants contain less potash than the bolls, while the potash is more concentrated in the leaves than in the bolls in the American plant. Similarly, the leaves of *desi* contain less potash and more sulphur and magnesia than the leaves of the American plant. These differences between lime, sulphur and potash contents in the two varieties have come out to be statistically significant. There are also some small differences in the contents of other minerals in the bolls and leaves of the two varieties as can be seen from Table III. For instance, the bolls of the *desi* plant contain slightly higher percentages of potash, magnesia and sulphur than the bolls of the American plant.

TABLE III

Quantities of minerals and nitrogen in gm. in different parts of the cotton plant

Variety	Plant part	Dry matter	Ash	N_2	K_2O	CaO	MgO	Al_2O_3 + Fe_2O_3	P_2O_5	SO_4	Cl_2
				Gm. per each plant part							
American . (24-12-35)	Root	31·6	0·99	0·17	0·37	0·20	0·07	0·01	0·04	0·10	0·09
,, .	Stem	319·5	12·75	2·31	4·60	2·92	0·98	0·05	0·54	1·64	0·78
,, .	Leaf	245·0	41·60	5·41	7·84	14·63	1·62	0·34	1·02	9·51	1·01
,, .	Bolls	268·5	14·13	6·62	5·12	1·62	1·12	0·10	1·42	1·71	0·84
Desi . . (26-11-35).	Root	28·5	0·97	0·13	0·31	0·26	0·07	0·01	0·03	0·08	0·08
,, .	Stem	153·5	6·54	0·96	1·43	2·10	0·49	0·03	0·15	0·60	0·42
,, .	Leaf	135·3	24·37	3·06	2·60	8·75	1·01	0·16	0·44	6·53	0·51
,, .	Bolls	234·8	13·93	5·11	5·22	1·91	1·21	0·17	1·20	1·90	1·06
				Gm. per 100 gm. of each plant part							
American . (24-12-35).	Root	100	3·14	0·56	1·17	0·63	0·23	0·04	0·13	0·33	0·28
,, .	Stem	100	3·99	0·72	1·41	0·91	0·31	0·02	0·17	0·51	0·24
,, .	Leaf	100	16·98	2·21	3·20	5·90	0·66	0·13	0·41	3·88	0·41
,, .	Bolls	100	5·27	2·47	1·91	0·61	0·42	0·04	0·53	0·64	0·31
Desi . (26-11-35)	Root	100	3·42	0·45	1·08	0·90	0·24	0·05	0·11	0·28	0·26
,, .	Stem	100	4·26	0·63	0·93	1·37	0·29	0·02	0·10	0·39	0·27
,, .	Leaf	100	18·01	2·26	1·92	6·47	0·75	0·11	0·32	4·83	0·38
,, .	Bolls	100	5·94	2·18	2·27	0·82	0·52	0·07	0·51	0·81	0·45

Composition of ash of the cotton plant

The percentage of each mineral in the ash of the plants of the two varieties was determined to see if there was any difference in the relative amount of the minerals that make up the ash of each plant. This method of expressing the results will indicate more correctly the differences in the mineral composition of the plants than the results calculated as percentages in dry weights. The ash of both the plants contains highest amounts of lime, potash and sulphates and the differences found in the contents of the three minerals in the two varieties, on percentage dry matter, are again seen on percentage ash basis.

TABLE IV

Percentage composition of ash of the cotton plant and of the different parts

Variety	K_2O	CaO	MgO	Al_2O_3 + Fe_2O_3	P_2O_5	SO_4	Cl_2
			Gm. per whole plant				
American	25·75	27·85	5·46	0·71	4·34	18·65	3·92
Desi	21·08	28·44	6·07	0·82	3·99	20·01	4·52
			Gm. for each part				
American—							
Root	37·30	20·00	7·49	1·36	4·27	10·45	9·02
Stem	35·35	22·89	7·69	0·44	4·21	12·83	6·14
Leaf	18·35	35·10	3·89	0·78	2·41	22·85	2·44
Bolls	36·25	11·52	7·93	0·70	10·15	12·12	5·94
Desi—							
Root	31·58	26·43	6·93	1·43	3·13	8·37	7·66
Stem	21·84	32·07	6·85	0·44	2·37	9·25	6·43
Leaf	10·67	35·95	4·16	0·74	1·81	26·82	2·12
Bolls	38·02	13·95	8·69	1·34	8·53	13·67	7·65

The ash of the stem, root and bolls contains largest amounts of potash, while the ash of the leaves contains largest amount of lime and sulphur. The ash of the roots and the stems of the *desi* plant is richer in lime than the ash of the same organs of the American plant, while the reverse relations hold good in case of potash, magnesia and phosphoric acid.

The potash and magnesia remain accumulated in the stems and lime and sulphur remain accumulated in the leaves. All minerals except lime, sulphur and aluminium and iron are found in larger proportions in the ash of the bolls than in the ash of the leaves.

Minor elements present in the cotton plant

Sodium, manganese, copper and zinc were determined in different parts of the cotton plant of the two varieties (Table V). Sodium was found to occur in largest quantity amongst the four minerals, while the leaves contained maximum quantities of each mineral except copper which is found more in the bolls than in the leaves. This is expected as copper is known to occur in largest amount in the embryo of the cotton seed [McHargue, 1926].

TABLE V

Minor elements present in the cotton plant (mg. per 100 gm. of dry weight)

Parts of the plant	Na_2O		MnO		CuO		ZnO	
	American	*Desi*	American	*Desi*	American	*Desi*	American	*Desi*
Root .	71	42	0·8	0·9	0·6	0·7	1·4	1·7
Stem .	98	43	1·1	1·4	1·1	1·2	3·5	3·7
Leaf .	181	127	6·2	7·1	1·9	1·8	4·2	4·7
Boll .	21	28	1·9	3·0	2·8	3·1	2·4	2·7

The vegetative parts of the American contain more sodium than those of the *desi* plant. On the other hand, the bolls of the *desi* plant contain more of these four minerals than the bolls of the American plant.

§2. *Uptake of minerals by the cotton plant*

Uptake of potash, nitrogen and phosphoric acid

The potash contents of the root, the stem and the leaf decrease per unit dry matter as the plant grows, indicating a greater increase in the dry weight of each part in proportion to the uptake of potash from the soil (Fig. 1A). The potash contents of the root and the stem show a greater decrease than that of the leaves. Important differences between the two varieties are seen

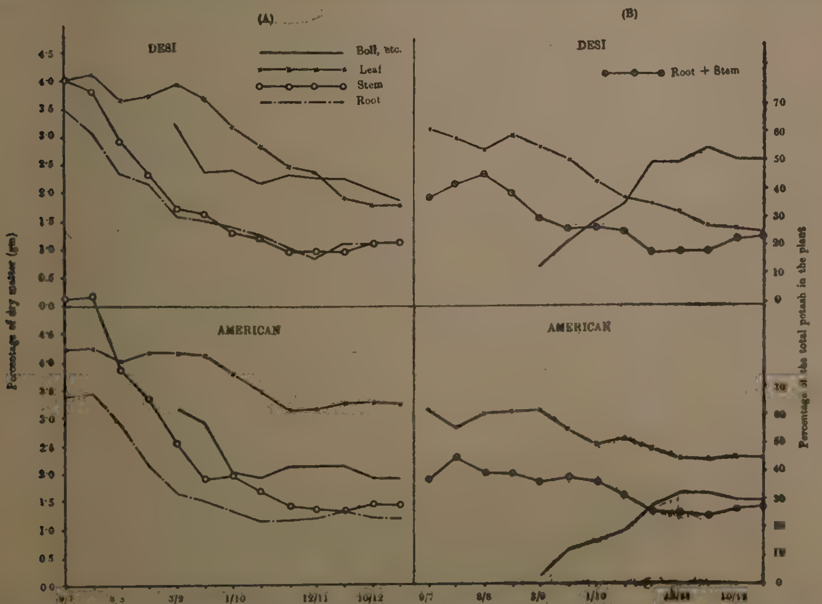

FIG. 1. (A) Potash in different parts ; (B) Distribution of potash in different parts

in the case of the leaves and the bolls.* The potash content of the leaves of the American plant does not show as marked a fall during the fruiting period as in the case of the leaves of the *desi* plant. The bolls of the *desi* contain at maturity more potash per unit dry matter than the leaves, while the leaves of the American plant contain more potash than the bolls at all stages. Thus the leaves of the *desi* get more depleted of potash than those of the American plant where it remains accumulated in the leaves.

The distribution of potash in different parts of the plant of the two varieties expressed as percentages of the total taken up by the plant shows similar features. The percentage of potash in the stem and root of the plant shows small decline in both cases. The amount of potash in leaves diminishes in the *desi* plant to a greater extent than in the leaves of the American plant. The most striking difference is in the bolls. The bolls of the *desi* plant contain at maturity 50 per cent of the total potash taken up by the plant, while the bolls of the American plant contain only 32 per cent of the potash found in the whole plant. This difference is partly caused by the greater percentage of dry matter of the bolls in the *desi* plant than that of the bolls of the American plant (Fig. 1B), and partly due to differences in the potash contents of the bolls in the two varieties (Table III).

The nitrogen contents of different parts of the plants of the two varieties show similar trends discussed above for the potash contents, with minor differences (Fig. 2A). The nitrogen in the stem and the root shows only a slight decline, while the decline in the nitrogen content of the leaves is

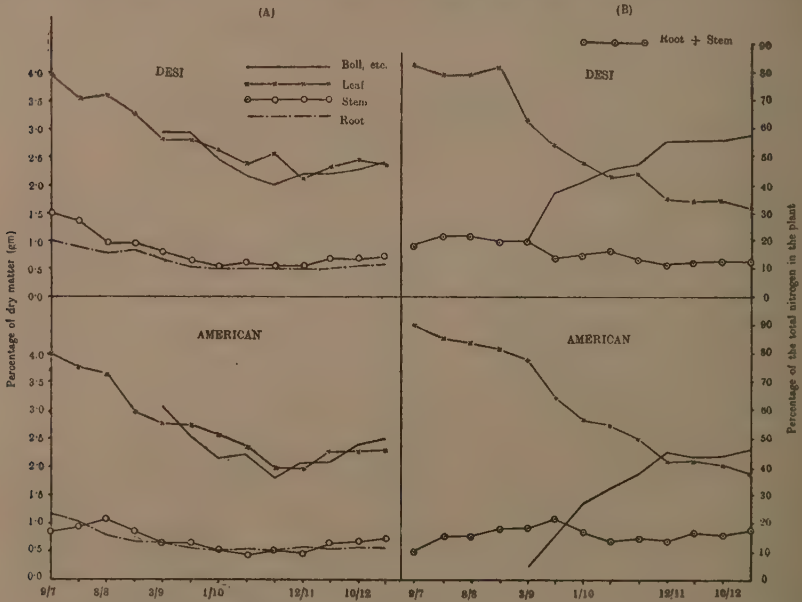

FIG. 2. (A) Nitrogrn in different parts ; (B) Distribution of nitrogen in different parts

*The term boll includes all buds, flowers and bolls produced on the plant up to the date of collection.

great (from 4·0 per cent to 2·0 per cent). The mature bolls and leaves contain nearly equal quantities of nitrogen per unit dry matter. It will thus mean that potash migrates to the bolls from the stem and roots and partly from the leaves (more in the case of the *desi* plant than in the case of the American plant), while nitrogen mostly travels to the bolls from the leaves.

The percentage distribution of nitrogen in different parts of the plant supports the same conclusions. There is no change in the percentage distribution of nitrogen of the stem and roots at the bolling stage, while the percentage of nitrogen in the leaves falls from 90 per cent to 38 per cent in the American plant and 80 per cent to 30 per cent in the *desi* plant. The leaves and bolls of the American plant at maturity have nearly equal percentages of nitrogen distributed between them, while the bolls of the *desi* plant contain a greater proportion of total nitrogen than the leaves (Fig. 2B).

The changes in the phosphoric acid contents of different parts of the cotton plant are similar to those discussed above for nitrogen with one difference that the phosphoric acid contents of the bolls are higher than those of the leaves in both the varieties. The bolls of the American plant contain slightly more phosphoric acid than the bolls of the *desi* plant per unit dry matter, and these differences are found to be significant (Fig. 3A). But the percentage of phosphoric acid that enters the bolls of the *desi* plant is higher (65 per cent) than in the case of the bolls of the American plant (55 per cent) (Fig. 3B). The leaves of both the varieties are found to get depleted of its phosphoric acid at fruiting stage. There are greater differences in the percentage distribution of phosphoric acid between bolls and leaves in the case of the *desi* plant than what is found between the same organs of the American plant.

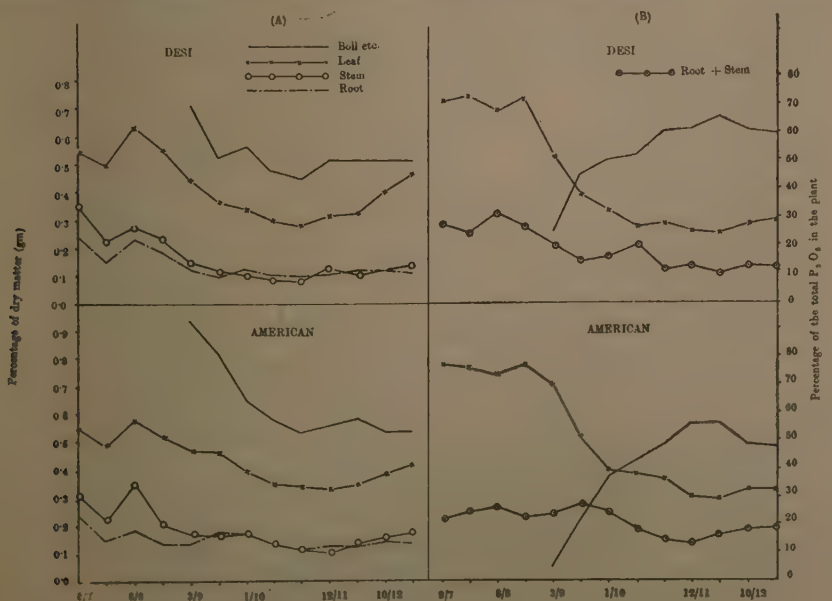

FIG. 3. (A) P_2O_5 in different parts ; (B) Distribution of P_2O_5 in different parts

The uptakes of these three important elements by the two varieties at different stages of growth and expressed as percentage of the total quantities taken up by each plant reveal interesting features. The maximum amounts of the three elements are taken up at the flowering to fruiting stage, i.e. middle of August to the end of September. The maximum is reached a fortnight earlier (15 September) in the case of the American plant than in the case of the *desi* plant (1 October) (Fig. 4A). The uptakes of the three elements appear to be more irregular in *desi* than in American, but the trend is almost the same in both the cases. There is negative uptake of potash in the *desi* plant and a secondary rise in the uptake of nitrogen and phosphoric acid in the American plant in November-December. In the case of the *desi* plant there is also an indication of a secondary rise in the uptake of the three elements at the end of October. Between 20 August and 30 September the American cotton plant takes up from the soil nearly 66 per cent of its total potash, 52 per cent of its total phosphoric acid and 45 per cent of its total nitrogen.

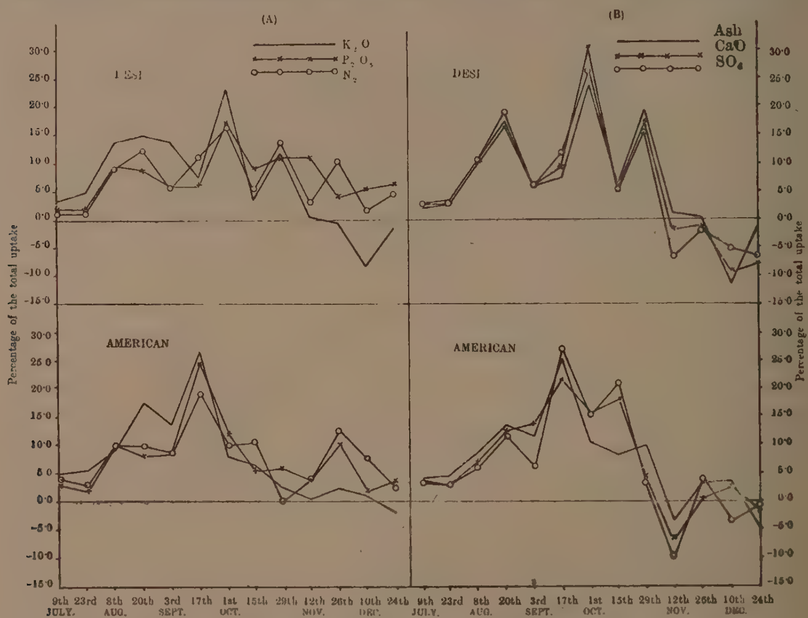

Fig. 4. Absolute uptake of minerals by American and *desi* cotton plants

Uptake of lime and magnesia

Lime contents of all the vegetative parts show very minor fluctuations at different stages of growth in both the varieties of cotton, indicating a continuous absorption of that mineral from the soil. The maximum amounts of lime are found in the leaves at all stages (Fig. 5A). There is very little migration of lime from the leaves to the fruiting parts as very small decrease in the percentage of lime in the leaves during the reproductive phase is visible (Fig. 5B). The percentage distribution of lime at all stages in the stem+roots also

remains constant. The bolls of the *desi* plant contain slightly higher percentage of lime than the bolls of the American plant.

The uptake and distribution of magnesia in different parts of the plants differ in some respects from the uptake and distribution of lime. The magnesia contents of the roots and stems fall in the pre-flowering stage, while that of the leaves continue to fall in the flowering and fruiting stage as well. There is more magnesia per unit dry weight in the leaves than in the bolls (Fig. 6A). The great decline in the magnesia content of the leaves is also evident from the curve of percentage distribution of that mineral in the leaves of the two varieties. For the bolls it is a rising curve and for the leaves it is a falling curve, while the curve for the roots+stems shows only minor fluctuations (Fig. 6B). Thus the leaves are found to get depleted of its magnesia at the flowering-fruiting stage.

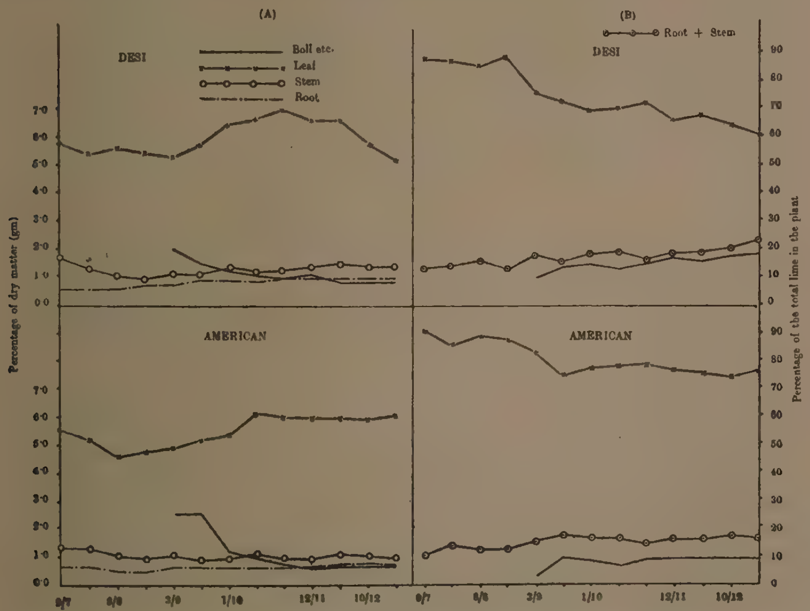

Fig. 5. (A) Lime in different parts ; (B) Distribution of lime in different parts

Maximum quantities of lime and magnesia are absorbed by the two varieties at the flowering stage, the peak of the maximum is reached a fortnight earlier in the case of the American plant than in the case of the *desi* plant (Figs. 4B and 7B). In the case of the *desi* plant secondary maximum in the uptake of lime is also found at the pre-flowering stage and at the fruiting stage, while these are not so pronounced in the case of the American plant. There is also negative absorption of lime in November in both the varieties after which a small and temporary rise in the uptake is again observed. The secondary maxima in case of magnesia are not pronounced in any variety though there is a decline in the absolute uptake with a rise again in November-December.

Uptake of iron and aluminium

Unlike other minerals the iron content of the roots is higher than that of the stems. The iron contents of the leaves, like lime and other minerals, are highest. There is a gradual fall in the iron content of the leaves, while the fluctuations in the same mineral in the roots and stems are less marked. The bolls of the *desi* plant contain greater amount of iron than the bolls of the American plant (Fig. 8A).

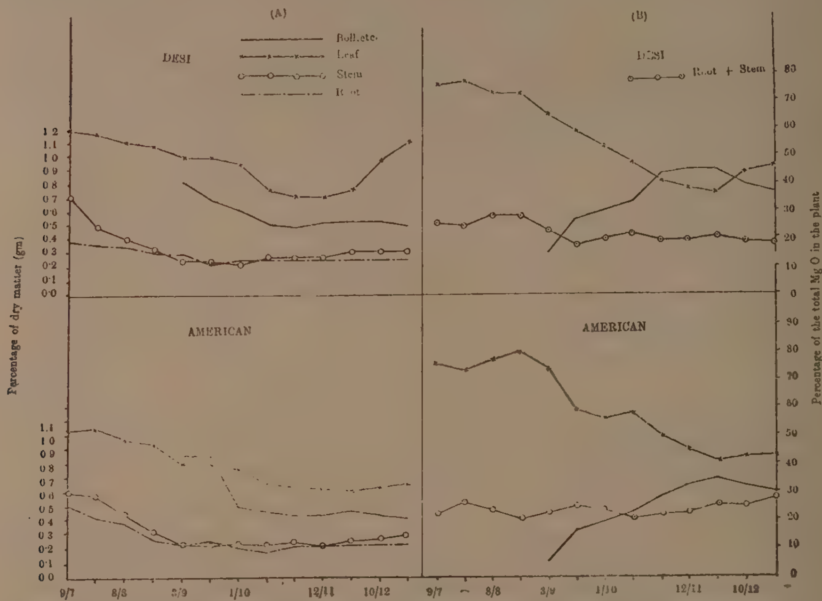

FIG. 6. (A) MgO in different parts ; (B) Distribution of MgO in different parts

The leaves show depletion of iron at the flowering-fruiting stage. The decline is greater in the case of *desi* than in the case of American (Fig. 8B). As a result, the iron content of the leaves of the American plant remains very high at maturity, indicating that like potash the leaves do not get depleted of this mineral. The bolls of the *desi* plant contain more iron (50 per cent of the total) than the bolls of the American plant (25 per cent of the total).

The trend in the uptake of aluminium in the two varieties is slightly different from that of iron. All parts show decreases in aluminium at pre-flowering stages, after which no further fall is evident (Fig. 9A). The percentage distribution of aluminium in different parts show the same features dicussed above for iron and they are therefore not stated here.

The absolute uptake of aluminium and iron at different stages of growth show some departures from the uptake of other minerals so far discussed (Fig. 7A). The maximum uptake as compared to other minerals occurs a month and a half earlier, i.e. in the pre-flowering stage, in the *desi* plant and a month earlier in the case of the American plant. The maximum is reached, unlike other minerals, earlier in the *desi* plant than in the American plant. The *desi* plant passes through another period of high uptake of these minerals during the fruiting phase. In both the varieties there is negative absorption

of these minerals in the month of November with a small positive rise again in December in the American plant.

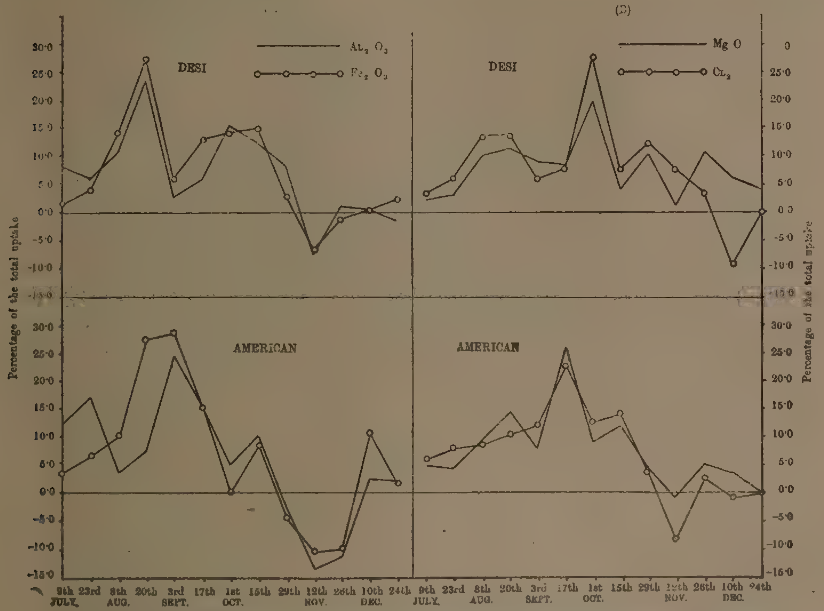

FIG. 7. Absolute uptake of minerals by American and *desi* cotton plants

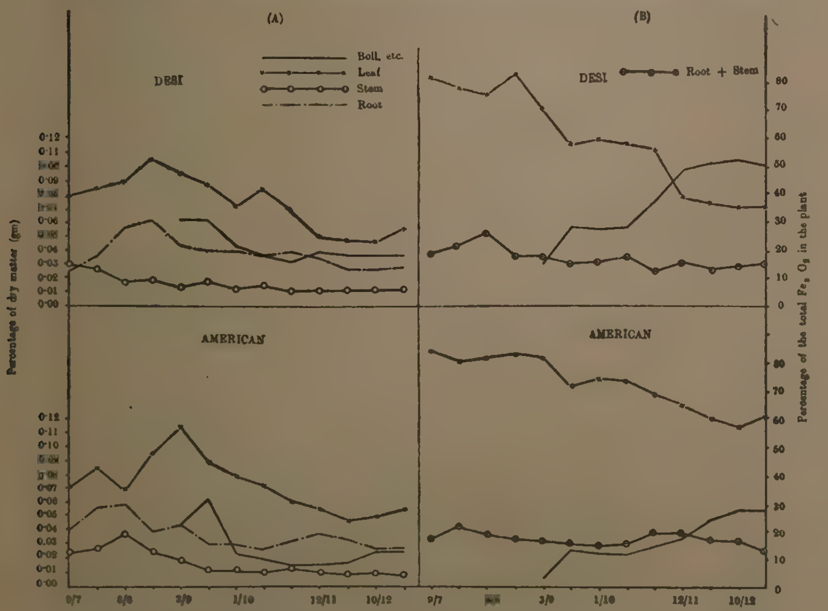

FIG. 8. (A) Fe_2O_3 in different parts; (B) Distribution of Fe_2O_3 in different parts

Uptake of sulphates and chlorides

The uptake and distribution of sulphates in the two varieties closely resemble the trends already discussed for the uptake and distribution of lime.

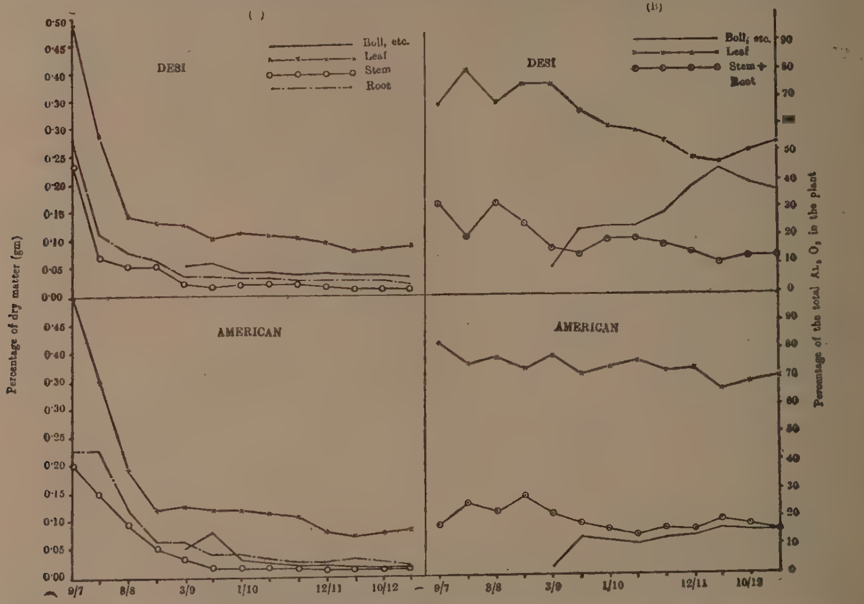

FIG. 9. (A) Percentage of Al_2O_3 in different parts of cotton plant ; (B) Distribution of Al_2O_3 in different parts

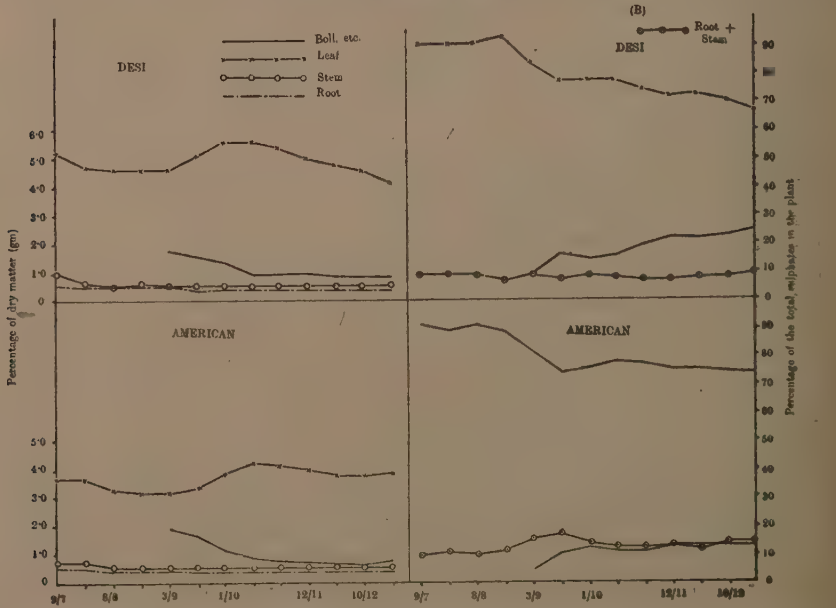

FIG. 10. (A) Percentage of sulphats in different parts ; (B) Distribution of sulphates in different parts

The close similarity between the two can be readily seen by studying the curves for lime and sulphates given in Figs. 5A and 10A. Sulphur remains accumulated in the leaves which contain 70-75 per cent of the total sulphates taken up by the *desi* or the American plant (Fig. 10B). Thus, like lime, there is very little migration of sulphur from the leaves to the fruiting parts. The percentage distribution of sulphates in the bolls of *desi* is higher than in the bolls of American.

The chloride contents, on the other hand, per unit dry weight, diminish as growth proceeds, in all the parts of the plant of the two varieties (Fig. 11A). Like magnesia, the curves for chlorides show steep falls in all the vegetative parts, in the pre-flowering stages. During the flowering-fruiting stages the decline in the chloride content of the leaves continues, while the decline is very small in the stems and the roots of the *desi* plant and it does not occur at all in the stems and the roots of the American plant (Fig. 11A). The relative distribution of this mineral in the different parts of the plant shows again the same features discussed for potash, magnesia, iron and aluminium (Fig. 11B). The chloride content of the leaves falls as it migrates to the bolls. In the case of *desi*, the bolls contain a greater percentage of chlorides than the leaves, while the reverse is the case in American variety.

The maximum uptakes of sulphates and chlorides occur during the flowering stage ; the peak of the maximum is reached a fortnight earlier in the American plant than in the *desi* plant (Figs. 4B and 7B). The curve for sulphates follows the same trend as the curve for lime, and the curve for chlorides shows the same trend as the curve for magnesia. The negative absorption of chlorides occurs a fortnight earlier in the American plant than in the case of the *desi* plant, while this is not the case with sulphates in the two varieties.

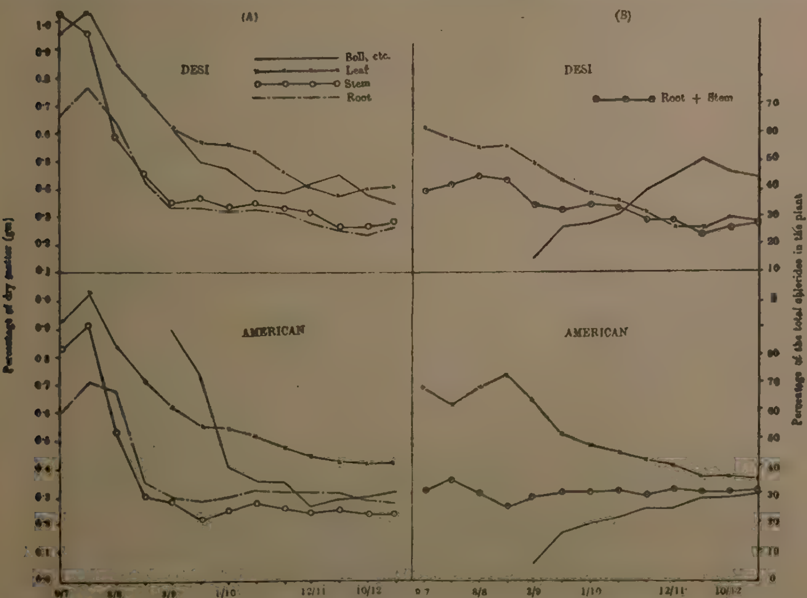

Fig. 11. (A) Percentage of chlorides in different parts of cotton plant ; (B) Distribution of chlorides in different parts

Uptake of total ash constituents

If all the minerals composing the silica-free ash of the two varieties are taken together, it is noticed that they follow the same trend in the uptake and distribution in the different parts as the minerals like lime and sulphates in the two varieties and potash also in the case of the American plant. This is due to the greater proportions of lime and sulphates present in the ash of the plant in relation to other minerals. The total ash shows a decline in the stem and the roots in the pre-flowering stage, but this was not the case with lime or sulphates.

The curves for the absolute percentage uptake of ash constituents per plant show the same trends as the curves for lime or sulphates (Fig. 4B).

Relative rates of uptake of minerals in the two varieties

The relative rates of the uptake of different minerals were calculated by the formula stated before in order to see if there were any differences in the relative rates of uptake of the minerals between the two varieties. The curves show that the relative rate of uptake in each case for each mineral falls with time like the relative growth rate (Fig. 12A). There is an indication of higher relative rates of uptake of potash, nitrogen, lime, and phosphoric acid in the early stages in the American plant than in the case of the *desi* plant. No differences are noticed between the two varieties in the relative rates of uptake of the remaining minerals.

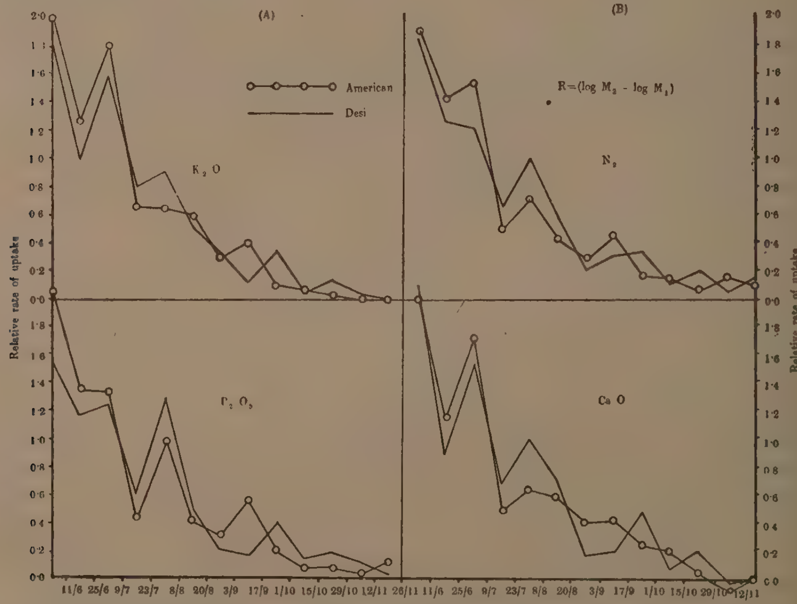

FIG. 12. Relative rates of uptake of different minerals and nitrogen

Increase and distribution of dry matter and moisture in different parts

The present study will not be complete without determining the increase and distribution of the dry matter in different parts of the plant of the two varieties. The maximum amounts of dry matter per plant are found in the bolls in the *desi* plant and in the stems in the American plant. The graphs (Fig. 13B) showing percentage distribution of dry matter in different parts

of the plant show that the *desi* plant produces more boll material than the American plant in proportion to their total dry weights. The American plant has greater percentage of dry matter in the stems than in the bolls. Thus,

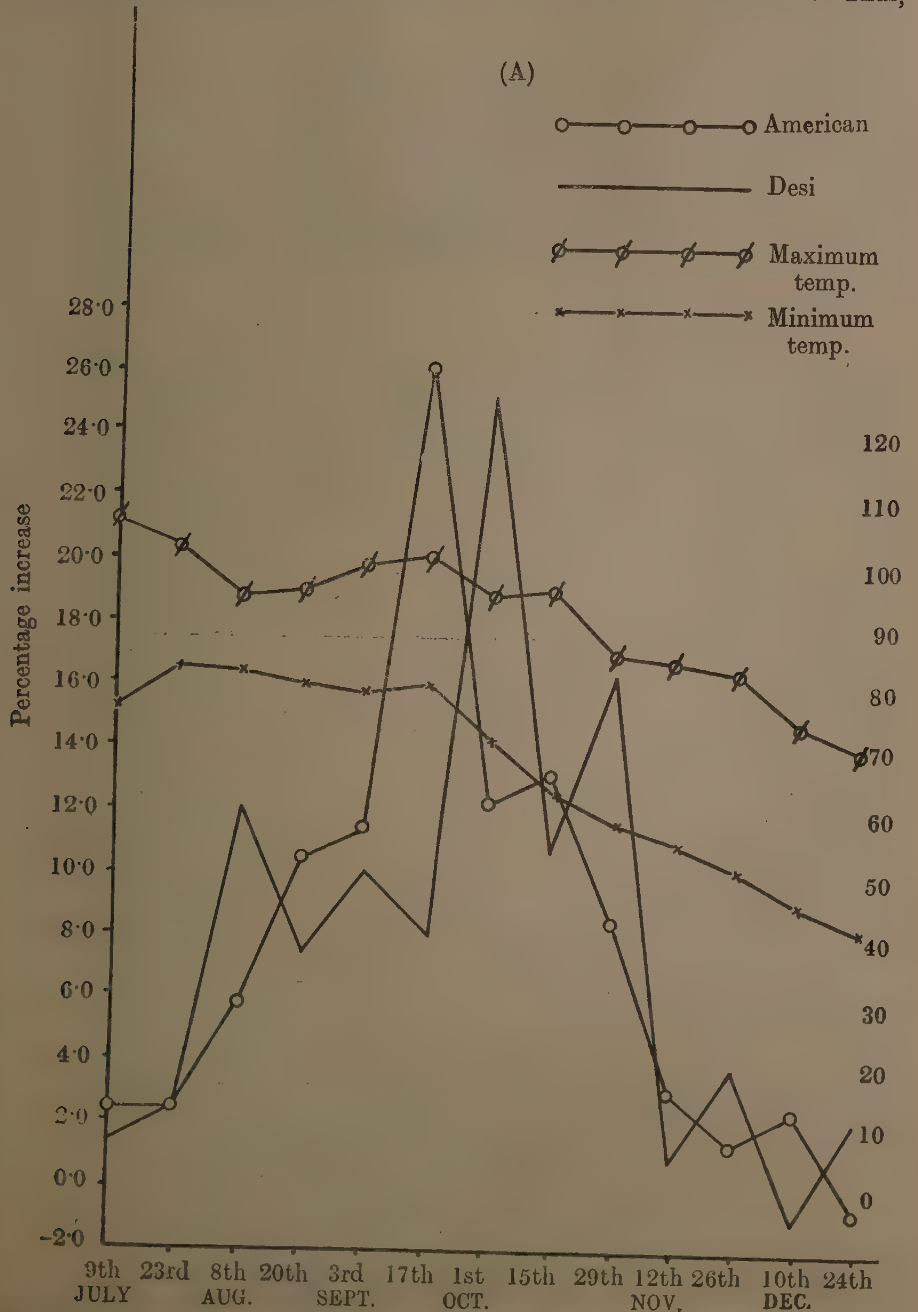

FIG. 13 (A). Percentage increase in the dry weight of plant at fortnightly intervals of American and *desi* cotton

the *desi* plant appears to be more efficient in boll production than the American plant (Fig. 13B).

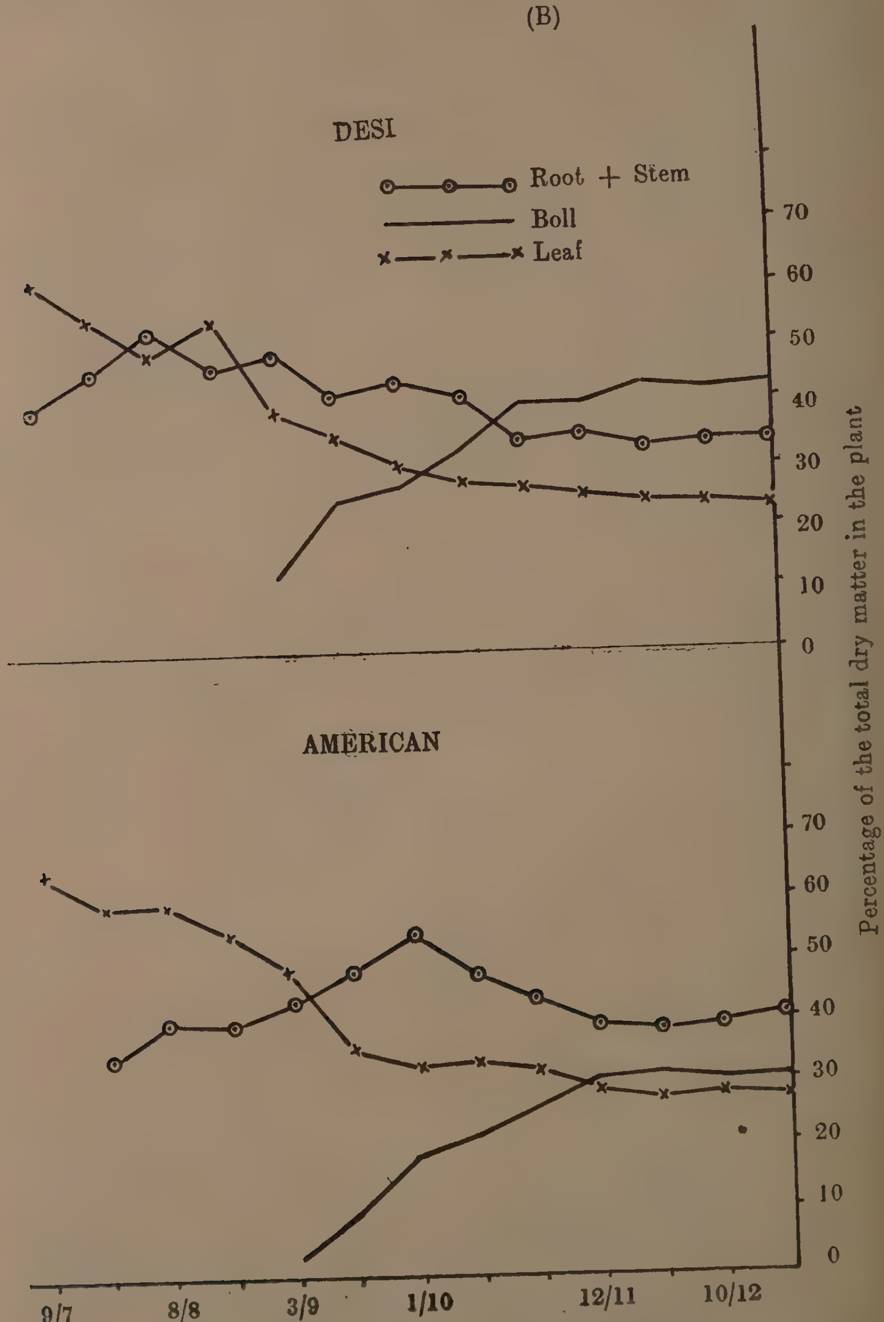

FIG. 13 (B). Percentage of dry matter in different parts

The percentage increase in the dry weight reaches its maximum in September in the case of the American plant and a fortnight later in the case of the *desi* plant (Fig. 13A). The maxima of the percentage increase in dry weights thus coincide with the maxima of the mineral uptake in the two varieties (except for iron and aluminium).

The moisture contents of the roots, stems, leaves and the bolls were calculated as percentages of dry matter in each case. The leaves and bolls are found to contain the highest amounts of moisture in both the varieties. The American plant contains more moisture in all its parts than the *desi* plant. It is a known fact that the fleshiness in plants is accompanied by a high potash content, while the plants that contain high calcium are generally more woody and contain less moisture. The differences in the moisture contents of the two varieties can therefore be correlated to the differences in their potash and lime contents.

Conclusions

Lime, potash and sulphates comprise nearly 70 per cent of the ash constituents that enter the cotton plant in the Punjab. Lime and sulphates enter the leaves in the largest amounts and remain accumulated there till senescence. The case of potash is different. The bolls contain more potash than the leaves in the *desi* plant, while the leaves contain more potash than the bolls in the case of the American plant.

At the time of fruiting the potash gets depleted from the stems, roots and leaves, while nitrogen and phosphoric acid get depleted mostly from the leaves. Thus the demand of the bolls for potash is met from all the vegetative parts of the plant, while the demand for nitrogen and phosphoric acid is met from the leaves only, with one difference that the depletion of potash from the leaves in the American plant is very little as compared with the *desi* plant. Lime and sulphates remain in the leaves at the time of fruiting, while no decrease in these minerals is also evident in the stem or the roots. Thus the bolls may be getting these minerals directly from the soil on account of their continued absorption from the soil.

It is also evident that magnesia travels from the leaves to the bolls at maturity and the same is the case with iron. On the other hand, aluminium gets depleted from all the parts and travel to the fruiting parts. Absorption of this mineral appears to fall off considerably in the pre-flowering stages as can be seen from the falls in the aluminium content of the leaves, roots and stems at that stage. The chlorides are found to behave like aluminium.

Thus, the demands of the bolls for lime and sulphates are met with from the soil, of potash mostly from the stems and roots and partly from the leaves, and of nitrogen, phosphoric acid, magnesia and iron mostly from the leaves alone, and of aluminium and chlorides from all the vegetative parts.

Maximum quantities of these minerals are absorbed by the two varieties at the flowering stages, the maximum point lying one stage earlier in the American plant than in the *desi* plant. The above conclusions hold good for both the varieties of cotton.

The distribution of different minerals and nitrogen in different parts of the cotton plant expressed as percentage of the total uptake of each reveals

important differences between the two varieties. As a rule the leaves of the *desi* plants get depleted of their minerals more than the leaves of the American plant. Side by side the same minerals are found to enter the bolls of the *desi* plant in greater amounts than in the bolls of the American plant. As for instance, the fall in the potash content of the leaves in *desi* is greater than in the American plant, resulting in a greater quantity of the same element appearing in the bolls of the former than in the bolls of the latter, so much so that the bolls of a *desi* plant contain more than 50 per cent of the total potash, while the bolls of the American plant contain only 32 per cent of the total potash present in the plant. Similar difference, though to a smaller degree, is seen in the case of nitrogen and phosphoric acid. Iron and aluminium reveal the same difference in the two varieties. The bolls of *desi* plant contain about 40 per cent of total aluminium and 50 per cent of total iron as compared with 15 per cent and 35 per cent of the two minerals in the bolls of the American. Chlorides also enter the bolls of the *desi* plant in a greater proportion than in the bolls of the American plant. Magnesia again shows the same behaviour. Thus, more of these minerals migrate to the bolls in the case of the *desi* plant than in the case of the American plant, where these minerals remain accumulated in the leaves.

The differences can be explained or interpreted in two ways. The *desi* plant produces more boll material than the American plant in proportion to their total dry weights, and the greater percentages of these minerals that are found in the bolls of the *desi* plant may be due to greater percentage boll production in that variety. The second explanation is that translocation of these minerals in the American plant is in some way interrupted. This interference in the migration of ions to the fruiting parts may be primarily caused by the relative deficiency of any one or more of the minerals. Thus the greater accumulation of these minerals in the leaves of the American plant as compared to the *desi* plant may either be due to low efficiency of the former for boll production or to some interference in their conduction to the bolls. The accumulation of potassium and other minerals in the leaves of the American plant may also be due to some physiological causes.

The above-mentioned fact regarding the accumulation of minerals in the leaves of the American plants at maturity as compared to the *desi* plant is of importance in understanding the mineral matabolism of the *tirak* plants. This will be discussed in another contribution on the subject.

Summary

The mineral composition of the different parts of the Punjab-American (4F) and *desi* (Mollisoni) cotton plants at fortnightly intervals is determined with an ultimate object of determining the nature of nutritional disorder that sets in the American plants when they suffer from *tirak* disease in the Punjab.

The quantities of different minerals in the American plant are as under, on percentage dry matter ; 2·2 gm. of CaO, 2·1 gm. of K_2O, 1·7 gm. of N_2, 1·5 gm. of SO_4, 0·35 gm. of P_2O_5, 0·44 gm. of MgO, 0·32 gm. of Cl_2 and 0·06 gm. of $Al_2O_3+Fe_2O_3$. The mineral composition of the *desi* plant is the

same except that there is less of K_2O (1·7 gm.) and more of CaO (2·4 gm.) and SO_4 (1·7 gm.) in this variety as compared with the American plant.

The percentage composition of ash of the two varieties shows the same differences as stated above.

Leaves and bolls contain largest amounts of all minerals. The leaves contain more potash than the bolls in the American, while reverse is the case in the *desi* variety. The mineral contents of the bolls of the *desi* plants are higher than the mineral contents of the bolls of the American plant.

Percentages of lime and sulphates in dry matter of the roots, stems and leaves remain nearly constant in both the varieties at all stages of growth. Nitrogen, phosphoric acid and iron contents of the leaves diminish, while potash diminishes more in the stem and root than in the leaves. The remaining minerals fall in all the parts as the plant matures. Thus the demand of the bolls for lime and sulphates appear to be met directly from the soil, and for potash, it is met mostly from the stems and roots and partly from the leaves in the *desi* plant only. Nitrogen, phosphoric acid and iron travel to the bolls from the leaves, and the remaining minerals from all parts of the plant to the bolls.

The maximum uptake of all minerals occurs at the flowering stages in both the varieties, the peak of the maximum being reached by the middle of September in American and by the end of September in *desi*. This is the period when the maximum increases in the dry weights of the plants are also found to occur in both the varieties.

The study of the distribution of minerals and nitrogen in different parts of the plant shows that the bolls of the *desi* plant contain more of each mineral than the leaves, while the leaves of the American plant at maturity contains greater percentages of the total minerals than the bolls. Thus, the important minerals like potash, magnesia, phosphoric acid, iron and aluminium and chlorides remain accumulated in the leaves of the American plant. This is not so in the *desi* plant. This difference between the two varieties may be due to the greater percentage of dry matter of the bolls per plant in *desi* than in American.

The case with nitrogen is different. The concentrations of nitrogen in the bolls and leaves in the two varieties are nearly the same. The percentages of total nitrogen in the leaves of the two varieties at maturity are also equal. These facts have a bearing, as will be shown later, on the *tirak* disease of the American cotton plant.

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*STUDIES ON THE PERIODIC PARTIAL FAILURES OF PUNJAB-AMERICAN COTTONS IN THE PUNJAB

IV. RELATION BETWEEN NITROGEN DEFICIENCY AND ACCUMULATION OF TANNINS IN LEAVES

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(With Plate XIII)

IN a previous contribution by the author [Dastur, 1939], it was shown that accumulation of a substance, belonging to the group of substances known as tannins, occurred in leaves of the 4F Punjab-American plants which later exhibited the symptoms of *tirak*, viz. premature yellowing and shedding of the leaves and cracking of the bolls which contain immature seeds and weak fibre. The accumulation of tannins was observed under the microscope as previously described in detail.

During the cotton season of 1937-38, the leaves of 4F cotton plants from a manurial experiment laid out in Square 32B of the Lyallpur Agricultural Farm were examined periodically for tannins from the month of July onwards. The manures used were all combinations of ammonium sulphate, potash and superphosphates. Control plots also were included. Microscopic examinations of four leaves of each of five plants under each treatment were made separately at about fortnightly intervals. The result of this investigation showed that there was a great accumulation of tannins in the leaves of plants grown on the control plots and on plots that had been manured with potash or phosphoric acid, while there was little or no accumulation of tannins in the leaves of plants on plots that had received ammonium sulphate, either singly or in combination with potash or superphosphate or both. In fact in many of the latter cases the leaves were found to be free from tannins. In plots to which no nitrogen had been applied the tannins were found to accumulate from the third week of August onwards. There was thus internally a marked difference between leaves of plants from nitrogen and no-nitrogen plots.

The leaves of plants from no-nitrogen plots also showed a great accumulation of starch in the palisade and spongy cells. The leaves collected at dawn showed the chloroplasts filled with starch grains which in many cases had ruptured the chloroplasts, as described previously [Dastur, 1939]. The leaves of plants from nitrogen plots were, on the other hand, either free from starch or contained only very small amounts.

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The results stated above suggested some relationship between starch and tannin accumulations in leaves and their nitrogen contents. This possible relationship was, therefore, investigated during the next cotton season.

Investigation

In the cotton season of 1938-39, two manurial experiments were laid out in Square 32D of Lyallpur Agricultural Farm. In the first experiment, 50 lb. of nitrogen in the form of ammonium sulphate was applied either: (1) at sowing time, (2) at flowering time, or (3) at both stages. Control plots were also included. In a second experiment in the same square (1) sulphate of ammonia and (2) green manuring were among the treatments. The leaves of plants from the nitrogen and no-nitrogen plots in both experiments were tested for tannins as described below.

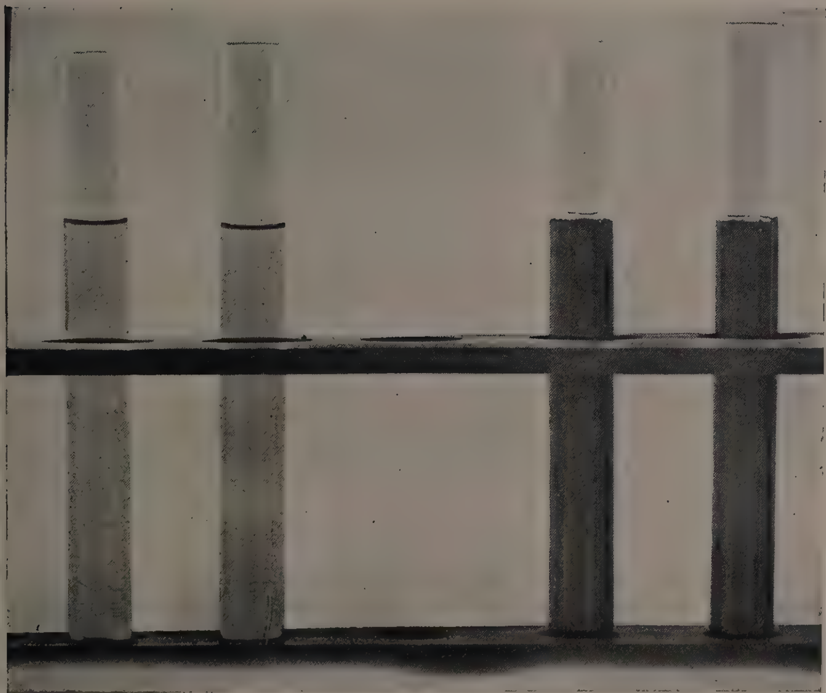
A leaf punch was used to cut out a circular area from a leaf. Such circular discs were cut out from four leaves at four nodes from each plant, each sample consisting of five plants selected at random. Thus, the total number and area of leaf-discs and the number and position of the nodes from which they were taken were kept constant. These tests were done in duplicate.

The leaf-discs were extracted with 25 c. c. of water for two hours in a water-bath kept at about 80°C. The extract was then filtered. The *p*H of the extract generally varied from 5·2 to 5·5. To 10 c. c. of the extract 2 c. c. of 0·02 per cent osmic acid was added. If tannins were present a black tinge in the colour of the extract was produced; otherwise, there was no change in the colour of the extract.

It may be pointed out in passing that the *p*H of the leaf extract bears a great relation to the development of the colour on adding osmic acid, if tannins are present. If the extract is made more acidic by the addition of an acid, a blue-green or greenish brown colour is produced within half an hour on adding osmic acid. If the extract is made alkaline by the addition of an alkali, a deep yellow to orange-red colour is produced. If tannins are not present in the extract, its colour does not change when osmic acid is added. In the tests for tannins which were carried out in this investigation the leaf extract was not acidified and a black tinge in the extract produced on the addition of osmic acid was taken as a positive test for tannin. If a blackish tinge in the colour of the extract did not develop, it was taken as a negative test for tannins (Plate XIII). The method described above is more rapid and time saving than the microscopic method of testing for tannins employed previously [Dastur, 1939].

The results of the tannin tests made in the plots of the two field experiments in this investigation are given in Table I.

The positive tannin test from plants grown in plots to which no nitrogen had been applied was not given by leaves till September. The results again showed that accumulation of tannins in leaves did not occur in plots treated with nitrogenous fertilizers. It was also again confirmed that inorganic fertilizers, like potash or superphosphate, had no effect on the accumulation of tannins in leaves as tannins were again found to be present in the leaves in plots treated with these fertilizers.



Negative (left) and positive (right) tests for tannins in the extracts of leaves with a high (3·53 per cent) and a low (2·14 per cent) nitrogen contents

TABLE I

Effect of nitrogenous fertilizers on the accumulation of tannins in leaves (Two replicates)

Treatment	Dates				
	9-9-38	21-9-38	29-9-38	7-10-38	20-10-38
Control	+ +	+ +	+ +	+ +	+ +
Green manure . . .	— —	— —	— —	— —	— —
50 lb. N as sulphate of ammonia at sowing	— —	— —	— —	— —	+ +
50 lb. N as sulphate of ammonia at sowing	— —	— —	— —	— —	+ +
50 lb. N as sulphate of ammonia at flowering	— —	— —	— —	— —	+ +
50 lb. N at sowing + 50 lb. N at flowering as sulphate of ammonia	— —	— —	— —	— —	— —

It was evident from the results stated above that the nitrogen metabolism of the plant had some relation with the accumulation of tannins in leaves. Steps were, therefore, taken to determine the nitrogen content of leaves of plants grown in the control plots and also in plots treated with sulphate of ammonia in the first field experiment.

Leaves of five plants from each plot in the first field experiment were collected and dried for determination of total nitrogen by Kjeldahl's method. Samples of leaves were collected in August, September and October at about fortnightly intervals. The same leaf material, which was used for the determination of total nitrogen, was also tested for tannins. It was found that it made no difference in the tannin test whether the leaf material was dry or fresh. The results of these determinations are given in Table II.

The total nitrogen content of the leaves of plants from the control plots was found to be at a lower level than the similar content of the leaves of plants of the same stage from plots that had received ammonium sulphate in August. There was thus an increased absorption of nitrogen by plants treated with the fertilizer as compared with the control plots. The total nitrogen of the leaves of the control plots fell to 1·76 per cent of the dry matter on 22 September, while it was maintained at a higher level in the leaves of plants from the manured plots, and varied from 2·5 to 3·1 per cent. This difference between the control and treated plots was also found in leaves collected in October.

Table II

Total nitrogen content of the leaves giving positive and negative tests for tannin

Plot No.	26 August 1938		20 September 1938		20 October 1938		Wt of seed cotton per boll in gm.	Yield in lb. per plot
	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin		
Controls								
1	2·58	—	1·82	+	1·46	+	1·56	15·8
4	2·99	—	2·26	+	1·62	+	1·55	13·1
16	2·54	—	1·71	+	1·57	+	2·06	15·6
20	2·82	—	1·65	+	1·22	+	1·85	18·8
39	1·97	+	1·51	+	1·23	+	1·61	16·6
50	2·42	+	1·71	+	1·15	+	1·84	16·3
62	2·52	—	1·71	+	1·31	+	1·31	15·4
Mean	2·55		1·76		1·36		1·68	15·9
50 lb. nitrogen at sowing time (16 May)								
18	3·34	—	3·15	—	2·32	+	2·15	31·0
13	3·22	—	2·81	—	2·31	+	1·83	25·6
49	*		2·65	—	1·85	+	2·44	35·5
32	2·69	—	2·20	+	1·75	+	2·16	36·2
45	*		2·69	—	1·70	+	2·21	32·3
59	3·46	—	2·67	—	1·98	+	2·36	31·0
52	2·98	—	2·66	+	2·03	+	2·22	32·6
64	3·27	—	2·85	—	2·01	+	2·31	35·3
Mean	3·16		2·71		1·99		2·21	33·4
50 lb. nitrogen at flowering (17 August)								
8	2·96	—	2·43	+	2·07	+	1·86	25·3
19	2·69	—	2·63	+	2·00	+	1·96	27·4
26	2·69	—	2·74	—	2·30	+	2·47	34·0
38	2·27	—	2·52	—	1·81	+	2·16	31·4
37	2·55	—	2·41	+	1·47	+	1·98	31·8
53	2·51	—	2·46	+	1·84	+	2·26	29·3
63	2·94	—	2·74	—	2·01	+	2·55	32·3
58	3·01	—	2·63	—	1·79	+	2·15	29·3
Mean	2·70		2·57		1·91		2·17	30·1
50 lb. of nitrogen at sowing + 50 lb. of nitrogen at flowering								
28	2·71	—	3·24	—	2·68	—	2·52	38·8
15	3·18	—	3·24	—	2·77	—	2·04	25·7
42	2·98	—	3·04	—	2·51	—	2·29	37·9
57	3·28	—	2·97	—	2·38	—	2·50	34·5
60	3·15	—	3·21	—	2·40	+	2·44	39·9
40	*		3·21	—	2·38	+	2·52	37·6
56	3·17	—	2·96	—	2·40	+	2·32	39·9
35	3·32	—	3·10	—	2·42	+	2·34	37·4
Mean	3·11		3·11		2·49		2·37	36·4

* Sample missing

The positive test for tannin was given by the leaves when the total nitrogen of the leaves fell in the neighbourhood of 2·5 per cent, while the test was negative when total nitrogen of the leaves was higher than 2·5 per cent. The leaves of the control plots gave a positive tannin test early in September, and this was accompanied by a low nitrogen level of the leaves. The negative test was generally accompanied by a high nitrogen level of the leaves. The values of total nitrogen in leaves giving a positive test were slightly higher than 2·5 per cent in two determinations, as seen from Table II, but such results are not unexpected as the leaf material is composed of all leaves, young and old, from five plants from the field. If the leaves of one of the five plants contain tannins with low nitrogen content, and if the leaves of the remaining four plants contain high nitrogen and no tannins, then the tannin test, which is a colour reaction, may be given but the average value of total nitrogen may come out higher than 2·6 per cent. This happens only in plots manured with sulphate of ammonia. The manure may not reach some plants on account of ununiform spreading of the fertilizer.

The nitrogen content of the leaves giving a negative test was found to be significantly higher than the nitrogen content of leaves giving a positive test for tannins.

Examination of sections of leaves under a microscope in the cotton season of 1937-38 showed that the accumulations of starch in the mesophyll cells occurred before the tannins were found. It was also observed that there was very little accumulation of starch in leaves from nitrogen plots, while starch and tannins were found in considerable amounts in the leaves of no-nitrogen plots. The starch content of the leaves from some of the plots of the first field experiment of 1938-39 was, therefore, examined, and it was found that while the starch content of leaves of plants manured with sulphate of ammonia was negligible, the starch content of leaves from manured plots varied from 2 to 6 per cent.

It is possible that starch accumulation in leaves occurs as a result of deficiency of nitrogen, when the carbohydrates synthesized in leaves are not as rapidly utilized for the synthesis of proteins. The surplus of carbohydrates that remains unutilized is stored as starch. It is also possible that the tannins are formed from carbohydrates. The tannin deposits and starch grains were found to occur in the same cell in the tissues of the leaves [Dastur, 1939]. In many cases tannins were seen covering the starch grains, both in the leaves and in the roots.

Accumulations of starch and tannins in leaves may not be the direct result of nitrogen deficiency, but may be due to deficiency of other minerals which are not absorbed by the plant in required amounts as a result of shortage of nitrates in the soils. It is a well-known fact that the absorption of one ion is governed, amongst many other factors, by the availability and absorption of another ion. When nitrogen is added to the soil, other ions may be absorbed in increasing proportions, thus resulting in the non-accumulation of starch or tannins in the leaves. It was noted previously that the addition of superphosphates and potash did not lessen the accumulations of starch and tannins in leaves or increase the yields. This indicates that there is no direct deficiency of these minerals in the soil. It is possible, however, that their absorption is limited by the low level of nitrates in the soils.

In order to investigate this point, the nitrogen, potash, phosphoric acid and lime contents of the leaves giving positive and negative tests for tannins, i.e. from the leaves of plants from the control and from plots manured with sulphate of ammonia were determined. The results are stated in Table III.

TABLE III

Mineral analyses of leaves giving a positive and a negative test for tannins

(Percentage expressed on dry matter)

Treatment	24 September				20 October			
	Nitrogen	Potash	Phosphoric acid	Lime	Nitrogen	Potash	Phosphoric acid	Lime
Control	1·71	4·28	0·421	4·81	1·31	3·16	0·310	4·38
50 lb. N at sowing time	2·85	4·82	0·481	5·32	2·03	4·09	0·354	5·32
50 lb. N at flowering stage	2·63	4·56	0·453	5·51	1·79	3·64	0·328	5·23
50 lb. N+50 lb. N (at sowing and flowering stages)	2·98	4·58	0·482	5·32	2·38	4·18	0·356	5·26

A study of the results showed that the potash and lime contents of the leaves of plots treated with sulphate of ammonia were higher than those of the leaves of control plots. There was thus an indication that increased absorption of nitrogen was accompanied by an increased absorption of potash and lime. Similar trends were noticeable from an analyses of leaves of plants made in the succeeding cotton seasons. It remains, therefore, unsettled whether deficiency of nitrogen or deficiency of other minerals due to their non-absorption in soils deficient in nitrogen was responsible for the observed accumulation of starch and tannin substances in the leaves. At any rate, the application of potash or phosphoric acid was not found to have any beneficial effect on the crop.

In Table II the yields of plots under different treatments are stated alongside the nitrogen content of the leaves and the tannin tests. It will be seen that the yields of control plots were lower than the yields of plots treated with nitrogen either at sowing time, flowering time or at both stages. Thus the addition of nitrogen had a marked effect on the yields of seed cotton. These results showed that the soil in the area concerned was deficient in nitrogen only, as the addition of other fertilizers in the second experiment had not resulted in increased yields. The detailed results of these field experiments will be discussed elsewhere. The application of nitrogen thus resulted in the non-accumulation of either starch or tannins and in increases in the nitrogen content of the leaves and in the yield of seed cotton.

The weight of seed cotton per boll was also found to increase as a result of the application of ammonium sulphate. The weight of seed cotton per boll in each plot was determined by weighing the seed cotton of bolls of five plants each in two separate units. The weight of seed cotton per boll was higher in plants treated with sulphate of ammonia than in the case of plants in the control plots. There was great improvement in the opening of the bolls as a result of nitrogen applications.

The relationship of tannins and nitrogen deficiency was again confirmed in the cotton season of 1939-40 by analysing the leaves from nitrogen and no-nitrogen plots in a complex field experiment laid out in Square 32C of Lyallpur Agricultural Farm. Tannin tests were made in three replicates of control plots and of plots that had received 50 lb. N as sulphate of ammonia on 14 August 1939. Three sowing dates were included in the experiment, and investigations were undertaken to see the time of appearance of tannins in the

TABLE IV

Accumulation of tannins in leaves of plants from nitrogen and no-nitrogen plots (Three replicates)

Treatments	Dates on which the leaves were tested for tannins (1939)						
	9 Aug.	25 Aug.	8 Sept.	20 Sept.	2 Oct.	14 Oct.	24 Oct.
Control plots—							
Sown on 12 May 1939	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Sown on 2 June 1939	— — —	+ — —	+ + +	+ + +	+ + +	+ + +	+ + +
Sown on 22 June 1939	— — —	— — —	— — —	+ — —	+ + +	+ + +	+ + +
Plots treated with sulphate of ammonia on 15-8-39-							
Sown on 12 May 1939	— — —	— — —	— — —	— — —	— — —	— — —	+ + +
Sown on 2 June 1939	— — —	— — —	— — —	— — —	— — —	— — —	+ + +
Sown on 22 June 1939	— — —	— — —	— — —	— — —	— — —	— — —	+ + +

leaves of plants sown at three different dates. The results of the tannin tests made on the fresh samples of leaves during the season are given in Table IV. Accumulation of tannins was first noticed in the control plots sown on 12 May and later in the control plots sown on 2 June and still later in plots sown on 22 June. Thus by delaying sowings the accumulation of tannins was also delayed from 9 September to 2 October, though the flowering phase in the third date of sowing was delayed only by a fortnight as compared with the date of flowering in the first date of sowing.

The leaves of plants in plots treated with sulphate of ammonia under the three sowing dates did not give a positive test for tannins till 24 October when the test is generally given by all cotton plants whether there is a deficiency of nitrogen or not. It must be noted that the nitrogen content of the leaves is as low as 2 per cent at that stage in all cases, except where very high doses of ammonium sulphate have been applied (Table II). In normal soils which are not deficient in nitrogen the nitrogen content of the leaves of 4F Punjab-American cotton was found to be about 2 per cent by the middle of October [Dastur and Ahad, 1941].

The nitrogen content of the leaves of plants in one replicate of the above experiment was determined (Table V). The leaves of five plants in each plot were dried in order to determine total nitrogen, as was done in the previous year. Tannin tests were also made from the same sample.

TABLE V

Total nitrogen and tannin tests of leaves of nitrogen and control plots at different stages

Date	Control plots								Nitrogen plots (50 lb. N on 14-8-39)							
	21 Aug. 1939		10 Sept. 1939		30 Sept. 1939		20 Oct. 1939		21 Aug. 1939		10 Sept. 1939		30 Sept. 1939		20 Oct. 1939	
(1939)	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin
12 May . .	2·14	+	1·63	+	1·50	+	1·31	+	2·47	—	2·84	—	2·12	+	1·76	+
2 June . .	2·20	+	1·73	+	1·60	+	1·32	+	2·67	—	3·04	—	2·52	—	2·11	+
22 June . .	2·98	—	2·39	+	1·97	+	1·81	+	3·53	—	3·33	—	3·32	—	2·70	—

The results showed that the nitrogen content of the leaves in the control plots was at a lower level than that of the leaves in the plots treated with sulphate of ammonia. The relationship between tannin and nitrogen deficiency in leaves was again established. In the plot sown on 22 June the nitrogen content of the leaves was at a higher level than that of the leaves in the early-sown plots.

Similar results showing the relationship of tannins and nitrogen content were obtained in other experiments, but, as there was no other special feature in those results, they have not been added here.

The yield of seed cotton from each plot and the weight of seed cotton per boll are given in Table VI.

TABLE VI

Yield of seed cotton per plot in lb. and weight of seed cotton in gm. per boll in nitrogen and no-nitrogen plots (1939-40)

Control				50 lb. N at flowering			
Plot No.	Date of sowing (1939)	Wt of seed cotton per boll in gm.	Yield per plot in lb.	Plot No.	Date of sowing (1939)	Wt of seed cotton per boll in gm.	Yield per plot in lb.
8	12 May .	0·91	6·25	3	12 May .	1·48	17·2
42	12 May .	1·11	8·75	13	12 May .	1·49	18·5
38	12 May .	0·98	7·50	45	12 May .	1·77	18·0
	Mean .	1·00	7·50		Mean .	1·58	17·9
57	2 June .	1·36	9·10	16	2 June .	1·39	17·7
62	2 June .	1·14	8·90	29	2 June .	1·72	22·1
15	2 June .	1·16	8·50	50	2 June .	1·90	21·1
	Mean .	1·23	8·80		Mean .	1·67	20·3
10	22 June .	1·23	7·25	7	22 June .	1·55	12·3
49	22 June .	1·52	12·50	23	22 June .	1·15	11·8
71	22 June .	1·48	11·25	39	22 June .	1·75	16·9
	Mean .	1·41	10·30		Mean .	1·48	13·6

In the control plots the yield and weight of seed cotton per boll improved as the sowings were delayed. The tannin tests also indicated that the deficiency of nitrogen arose later in the plots sown late. This was further supported by the results of nitrogen content given in Table V.

The yields from plots treated with sulphate of ammonia were higher than those from control plot sown on the same date, while the weight of seed

cotton per boll was higher than that from the corresponding control plots only in the first two dates of sowing. The plots sown on 22 June 1939 responded to a smaller extent to the application of sulphate of ammonia than in the other two cases. This was due to lack of vegetative growth, because of which the plants did not suffer from nitrogen deficiency as much as the plants sown earlier. Hence the last-sown plots had not profitted by the application of sulphate of ammonia to the same extent as the early-sown plots.

A detailed study of the above relationship between the accumulation of tannins, nitrogen content of the leaves and the yield, plot by plot, in the first field experiment of 1938-39 revealed that applications of sulphate of ammonia had not resulted in as high an increase in yield in some plots as in others though the tannin test was negative in September and the nitrogen content was higher in these plots than in the control plot. The results of such plots are given in Table VII.

TABLE VII

Yields and nitrogen contents of plots which have saline sub-soil

Plot No.	Treatment	Tannin test on 22 Sept. 1939	Percentage of nitrogen on 20 Oct. 1939	Weight of seed cotton per boll	Yields in lb. per plot
1	Control	+	1·46	1·54	15·8
4	Control	+	1·62	1·26	13·1
2	50 lb. N at sowing	—	2·78	1·50	20·5
7	50 lb. N at sowing	—	2·53	1·23	13·7
3	50 lb. N at flowering	—	2·65	1·74	23·5
54	50 lb. N at flowering	—	2·08	1·50	19·5
6	50 lb. N at each stage	—	3·12	1·50	21·5
15	50 lb. N at each stage	—	2·77	2·04	25·7

As the results show, there was not as great a response to nitrogen as in the results given previously. There was no increase in the weight of seed cotton per boll as compared with the control as a result of nitrogen application. A comparison of the results given in Tables II and IV with those in Table VII will show these differences.

Similar results were obtained in the plots of the second field experiment of 1938-39 when there was a smaller response in yield to nitrogenous fertilizers and there was no increase in weight of seed cotton per boll in the manured plots.

The physical and chemical analyses of the soils in these plots and of the soils of the fields of the second field experiment referred to above were made foot by foot down to a depth of 6 ft. It was found that the subsoil in all these cases either contained sodium clay or very high concentrations of free sodium salts at varying depths. These soil investigations and their effects on the growth and yield of the cotton plant will be described in another contribution on the subject. The application of nitrogenous fertilizers when such soil conditions exist do not greatly improve the yields or the opening of the bolls,

on account of other disturbances produced in the plant metabolism, though the deficiency of nitrogen does exist there along with saline subsoil.

Conclusions

The accumulation of tannins in leaves, as the results show, is found to occur when the nitrogen content falls below a certain level. If tannins are found in the leaves at the flowering stage of the plant, i.e. from the third week of August to the middle of September, it may be regarded as a biochemical index of nitrogen deficiency in the plant, as the nitrogen content of the leaves during that stage is found to fall to the level of 2·5 per cent or less. The cotton plant absorbs nitrogen and other minerals in maximum amounts during the flowering phase, as shown in a previous contribution [Dastur and Ahad, 1941]. This relationship between low nitrogen content of the leaves and the accumulation of tannins can be of practical value. If sulphate of ammonia is applied to a cotton crop when its leaves give a positive test for tannin at the flowering stage, the yield will greatly increase and the opening of the bolls will be greatly improved, except where the subsoil is saline. If nitrogen deficiency does not occur in the plants growing on saline subsoils, a positive tannin reaction will not be given. The difficulty arises only when both conditions occur together. In such a case a test for tannin will be positive, but the application of sulphate of ammonia may not result in as high an increase in yield as in the case when salinity does not exist.

The presence of salinity in the subsoil can be detected by the external appearance of the plants, as in such cases the plants are either stunted in growth or, if they are well grown, the leaves in August-September, about a week after irrigation, show drooping from which they do not recover. The leaves of plants growing on sandy and saline soils curl upwards, forming discs, and become bronze coloured in September. If a positive reaction for tannin is given by plants in such fields, sulphate of ammonia may not be applied. The desirability of modifying this test in such a manner that salinity in the subsoil can be detected apart from a deficiency of nitrogen in the soil is being examined.

Attempts were, therefore, made to put to a practical test the relationship between nitrogen deficiency and accumulation of tannin in leaves in the cotton season of 1939-40. The tests for tannins were carried out in fields of Lyallpur Agricultural Farm and in fields of zemindars. The test was made in duplicate samples of five plants each in the third and fourth weeks of August. Forty-five fields were tested and whenever a positive test for tannins was given, sulphate of ammonia was applied to those fields at the rate of 2 mds. per acre before the next irrigation. Some portions of each field were retained unmanured so as to serve as control. Whenever it was possible to do so, adequate replicates were provided, otherwise only two replicates could be kept. It is not possible to divide a standing crop into a large number of plots on account of various difficulties, such as the irregular stand of the crop, the shape and size of the field, difficulties of making strong bunds between plots and the situation of water channels which are important for irrigating the control and treated plots separately so that the water from the treated plots does not pass into the control plots.

Sulphate of ammonia was also added at the same rate in some fields where a negative test for tannin was given, for the sake of further confirmation of the

above relationship. It is interesting to see the increase in yield when the tannin test was negative.

At one centre sulphate of ammonia was added as late as 6 October. As already stated, all crops generally give a positive test in October and therefore it was a normal feature of leaves at that stage. It was, therefore, necessary to study the effect on yield of additions of sulphate of ammonia at the rate of $1\frac{1}{2}$ mds per acre as late as October. Four replicates were provided.

The mean yields of control and treated plots, the cost of the fertilizer (at pre-war rates) and the net profits after deducting the cost of fertilizer are given in Table VIII where a positive test was given and in Table IX where a negative test was given. The yields were recorded by the respective zemindars and were sent to the author, except in the case of the observations at Lyallpur Agricultural Farm.

TABLE VIII

Response to application of sulphate of ammonia to cotton crop, when a positive tannin test was given, at the flowering stage

Place	Square number	Variety	Mean yield per acre in mds		Cost of $(NH_4)_2SO_4$ per acre	Net profit* per acre
			Control	Treated		
					Rs. A.	Rs. A.
Lyallpur	Sq. 32C, Fds 1-4	4F**	7·27	13·21	15 0	44 6
,,	,, Fds 5-6	4F **	5·50	9·8	7 8	27 8
,,	,, ,,	*Desi* **	9·6	14·3	7 8	34 10
Okara	Chak 5A, Sq. 4	*Desi*	14·3	17·2	10 0	16 1
,,	,, Sq. 5	American	4·7	8·8	10 0	31 0
,,	,, Sq. 5	,,	6·3	8·3	10 0	10 0
,,	Chak 8, Sq. 16	289F/K25	7·2	10·8	10 0	26 0
,,	,, Sq. 21	289F/K25	9·0	11·5	10 0	15 0
,,	Chak 10, Sq. 38K	289F/K25	6·8	7·4	10 0	—4 0
,,	,, Sq. 35	*Desi*	15·2	20·7	10 0	45 0
,,	,, Sq. 56	43F	14·5	17·2	10 0	17 0
Average for Okara			9·8	12·7	...	19 0
Khanewal B. C. G. A.	Chak 83, Sq. 45	289F/K25	2·55	4·65	10 0	11 0
,,	,, Sq. 35	*Desi*	3·63	5·54	10 0	7 3
Abdul Hakim	8R/1R, Sq. 9	4F**	9·42	16·13	10 0	57 1
	Sq. 9	*Desi* **	9·93	13·34	10 0	20 11
Average of all experiments	......	...	7·21	11·21	10 0	27 11
Risalewala Seed Farm	Sq. Fertilizer applied on 6 October	L S S	3·36	3·86	7 8	—2 8

*For calculating net profit, the price for Americans is taken as Rs. 10 per md. and for *desi* as Rs. 9 per md. in 1939.
** = Replicated six times or more.

It is clear from the results that the application of sulphate of ammonia, when the positive test for tannin was given by a crop at the flowering stage, gave profitable returns, the actual gain depending on the price of the fertilizer, the market price of *kapas* and the stand of cotton. The seasonal conditions in October and a part of November were unfavourable during the season of 1939-40, otherwise it was expected that the increases in yields would have been higher than they were.

TABLE IX

Response to applications of sulphate of ammonia and other manures to cotton crops when negative tannin tests were given by the leaves at the flowering stage

(Replicated seven times or more)

Place	Square No.	Variety	Mean yield per acre (mds)			Net profit
			Control	Treated	Cost of fertilizer*	
					Rs. A.	Rs. A.
Lyallpur	$27D_2$	4F	3·4	4·0	15 0 (NP)	—9 0
,,	,,	,,	3·4	4·1	61 14 (G.M.+NP)	—54 14
,,	,,	,,	3·4	2·3	46 14 (G.M.)	—46 14
,,	$27D_1$	,,	13·44	13·05	15 0 (N)	—15 14
Khanewal B. C. G. A.	Chak 83, Sq. 32	289F/K25	1·51	1·71	10 0 (N)	—8 0
Montgomery	Farm	4F	1·02	1·13	15 0 (N)	—3 3

* G. M. = Green manuring, N = Sulphate of ammonia, P = Superphosphate

The results also showed that no benefit was derived from the application of sulphate of ammonia to fields where the leaves of the crop did not give a positive test for tannin. In some cases there was no increase in yield at all.

It was also of no benefit to apply sulphate of ammonia as late as October to crops even though a positive test was given.

These results are in conformity with the experience of the Department of Agriculture and other zemindars in their manurial experiments. The response to sulphate of ammonia varied in their experiments from year to year and field to field. At some places the use of sulphate of ammonia was found to be economical, whilst a contrary result was obtained at other places. Various large-scale zemindars in the Punjab have given up the use of sulphate of ammonia as they did not find it on the whole beneficial. The causes of the varying responses can now be traced to the soil conditions that are very variable in the Punjab. The presence of sodium salts in the soil and the application of sulphate of ammonia to fields in which it was not needed by the crop are the two chief factors that have made the use of sulphate of ammonia unprofitable. Crowther [1939] deplores the fact that cultivators in the Punjab do not use sulphate of ammonia for manuring their cottons, but they have reasons for not doing so as the present investigation has shown.

There are great practical possibilities in the relationship that has been established between nitrogen content of the leaves and the accumulation of tannins. It is not possible to ascertain by making chemical analysis of soils for available nitrogen whether a crop suffers from nitrogen deficiency or not. Even though the nitrate nitrogen in the soil is found to be nil in August or September by the phenoldisulphonic method, the yield may be normal. Again the crop yields were rather low or normal even though the nitrate nitrogen

varied in both cases from four to six parts per million at the flowering stage. These statements can be supported by data to be published later in another contribution, but the results given in Table IX also support them as the addition of extra nitrogen at the flowering stage of the plant did not result in increased yields. A plant is the best indicator of its wants which cannot be always determined by soil analysis alone. The tannin test described above makes the detection of nitrogen deficiency possible at an earlier stage, i.e. before the leaves externally show the symptoms of nitrogen starvation, such as yellowing and shedding. It also enables the cultivator to remedy the deficiency before it is too late.

It is possible that deficiency of nitrogen generally occurs in those fields where tannin tests are positive each year that the cotton crop is grown in them. The question whether it is possible by means of this test to label a field once for all time as one that will suffer from nitrogen deficiency whenever cotton is grown in it and will give an economic response to the application of a nitrogenous fertilizer is under investigation at present. So far the total nitrogen of the leaves of 4F Punjab-American cotton plants only has been determined. It is, therefore, not possible to say at this stage the level of total nitrogen in the leaves of other varieties and strains of cotton when tannins would appear in them, though some of those varieties and strains did give positive tannin tests, as can be seen from Table VIII, and responded to applications of sulphate of ammonia.

Summary

Formation of tannin deposits in the mesophyll cells of the leaves of the 4F Punjab-American cotton plants which later developed premature yellowing and shedding of leaves and bad opening of the bolls was described in a previous contribution by the author [Dastur, 1939].

In the cotton season of 1937-38, whilst making periodic examination of the leaves, it was noticed that these deposits were absent in plants from plots treated with ammonium sulphate, while they were present in the leaves of plants from the control plots and from plots manured with potash or superphosphate. It was, therefore, undertaken to investigate the possible relationship between the formation of tannins in leaves and their total nitrogen content in the season of 1938-39.

Microscopic method for testing the presence of tannins in leaves was replaced by a chemical method.

Leaves of plants from two field experiments, in which nitrogenous fertilizers were among the treatments, were tested periodically for tannins and it was found that a test for tannins was given by the leaves of plants from the control plots by the beginning of September, while the test was negative in leaves of plants from plots manured with nitrogenous fertilizers.

Analysis of the leaves for total nitrogen showed that the nitrogen content of the leaves giving a negative test was significantly higher than the nitrogen content of the leaves giving a positive test. Similarly the yield and the opening of the bolls, i.e. weights of seed cotton per boll were higher of the manured plots than of the control plots.

The above relationship between tannins and nitrogen deficiency was again confirmed in the cotton season of 1939-40.

A positive tannin test was generally given by leaves, whose nitrogen content was in the neighbourhood of 2·5 per cent of the dry matter. By sowing the cotton crop later than the normal practice tannins developed later in the leaves than in the leaves of early-sown plants. The analysis of the leaves under different sowing dates again confirmed the same relationship between the nitrogen content of the leaves and tannins.

A positive test for tannins in leaves of the cotton plant in the Punjab at its flowering phase (August-September) is thus an index of nitrogen deficiency at that stage. This fact was made use of in detecting and remedying the nitrogen deficiency in cotton crops during 1939-40 season. The test for tannins was made in 45 fields located in different districts in the third and fourth weeks of August. Whenever a positive test was recorded, sulphate of ammonia at the rate of 2 mds per acre was applied. Controls were also included. The fertilizer was also applied in some fields where negative test was given. In the former case the response to the fertilizer was high and profitable, while in the latter case the response was either nil or low and was uneconomic.

Practical possibilities of this test are discussed.

Acknowledgements

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FOOT-ROT OF GRAM (*CICER ARIETINUM* L.) CAUSED BY *OPERCULELLA PADWICKII* NOV. GEN., NOV. SPEC.

BY

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(With Plate XIV)

IT has recently been proved by Prasad and Padwick [1939] that a wilt disease of gram (*Cicer arietinum* L.) is caused by a species of *Fusarium*. During the season 1938-39 a considerable number of wilted plants collected by Mr K. M. Dutt from Karnal (Punjab) yielded on isolation a quite different fungus which in culture produced pycnidia with spores of a very curious form. In the season 1939-40 this same pycnidial fungus was isolated from many diseased plants at the Imperial Agricultural Research Institute, Delhi. Taking the results of isolations at Karnal and Delhi together, the pycnidial fungus was obtained from eight out of nine varieties of gram, and 85 isolates of it were obtained as compared with 111 isolates of *Fusarium*.

Inoculation experiments

Inoculation experiments were made by three different methods :—

(1) By immersion of seeds in a suspension of spores made from a culture of the fungus.

(2) By sowing the seeds in sterilized soil infested with cultures of the fungus grown on a sterilized mixture of soil and corn-meal.

(3) By spraying the foliage with a spore suspension.

From repeated experiments made so far it has been possible to obtain heavy infection regularly only by method 2 (soil infestation). With 25 different varieties, death of seedlings varying from 14 to 81 per cent was obtained, while the control plants remained healthy. Re-isolations of the same fungus were made from the infected plants. By method 1 (immersion of seeds in a spore suspension) only a small number of plants took infection, while method 3 (spraying the foliage with a spore suspension) was unsuccessful.

Symptoms of the disease

The affected plants begin to dry from the tip downwards. The leaves assume a pale green colour, and later become yellowish and finally drop off. The collar of the plant becomes dark brown in colour and in some cases the roots and rootlets are also attacked. Microscopic examination of stem and root tissue reveals broad granular inter and intra-cellular septate mycelium within the tissues of the host. The fungus does not directly attack the foliage as in the case of blight (*Mycosphærella rabiei* Kovachevsky). No fruiting bodies have been found on the host either in nature or in artificial inoculation experiments. Various attempts were made to induce the causal organism to produce its fruiting bodies on its host. The pieces of infected material

FIG. 1
Pycnidium with open lid (×24)

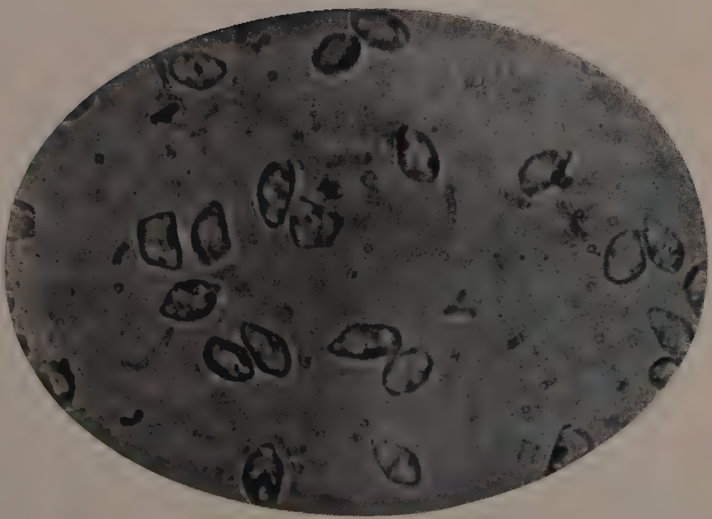

FIG. 2. Pycnidiospores (×750)

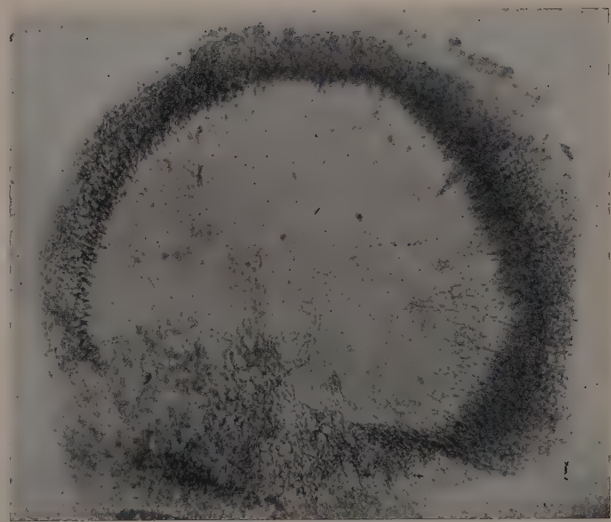

FIG. 3. Section of pycnidium, showing branched conidiophores with a lateral conidium still attached (×205)

were held at different temperatures ranging from 10 to 30°C. for a period of eight months and were examined periodically, but the attempt was unsuccessful. Some of the infected material was buried in pots which were watered once a week to keep the soil wet and examined every fortnight. After about three months, pycnidia of the fungus developed on some of the infected pieces.

The fungus

On oat-meal agar or potato dextrose agar the fungus produces a white felt of mycelium on the substratum, and at the end of a week yellowish, immature pycnidia develop, at first immersed and later erumpent. The pycnidia are not produced in a stroma. At first they are yellow, but at maturity they become carbonaceous, and a yellowish-white spore mass oozes out from the ostiole, or alternatively the upper portion of the pycnidium is forced off as a lid remaining attached at one side so that the structure appears as a hinged shield (Plate XIV, fig. 1). They may measure up to 800μ in diameter. The spores (Plate XIV, fig. 2), which are produced in great abundance, are quite irregular in shape, hyaline, and borne on two kinds of conidiophores, the shorter being unbranched and of average length 83μ, forming a compact layer on the entire inner surface of the pycnidium, the longer ones being sparsely branched and sometimes septate and producing the spores laterally on minute sterigmata (Plate XIV, fig. 3).

The fungus, belonging to the Sphæropsidaceæ, has certain peculiarities which make it difficult to place it in any known genus.

Three fungi have been described which have irregularly shaped pycnidiospores. Tassi [1900] described a new genus *Trigonosporium* with a single species (*T. australiense*). The pycnidia are sub-globose, sub-cutaneous erumpent, perforated with an apical pore, and 200-250μ in diameter. The spores are distinctly triangular when viewed from above, ellipsoid to cylindrical when seen laterally, and measure 4-5μ in diameter. The genus *Vanderystiella*, described by Hennings [1908] is represented by a single species *V. leopoldvilliana*. It has round to disc-shaped, angular, dark acervuli, 60-130μ in diameter; short hyaline conidiophores; and fusoid to quadrangular, pointed, hyaline to dark conidia, 10-14 × 5-7μ in size. A species of *Phomopsis*, namely *P. Boycei*, described by Hahn [1930] also has irregularly fusoid spores with salient angles, so that they become three or four sided. They are borne in ecto-stromatic, simple or compound imbedded pycnidia, the longer ones being 'plurilocular, the chambers fusing irregularly and tending to form a unilocular cavity lined with a convoluted hymenium.'

Although all these fungi possess one or more characteristics which are reminiscent of the gram wilt fungus, none has a non-stromatic pycnidium with a circumscissile lid and containing irregular hyaline spores, and there seems to be no genus so far described in which such a fungus can be included. It is proposed to erect a new monotypic genus to encompass the characteristics of this fungus, and to call it *Operculella* on account of its peculiar method of liberating spores.

Operculella gen. nov.

Pycnidia unilocular, discoid to sub-globose, immersed at first, later erumpent, opening with an apical pore or by means of a hinged lid. Conidiophores of two kinds; the shorter ones simple, lining the walls of the pycnidium

and bearing spores terminally; the longer ones branched and sometimes septate and bearing spores laterally as well as terminally. Spores irregular in shape, continuous, hyaline.

Latin diagnosis

Pycnidia unilocularia, discoidea vel sub-globosa, primo immersa, dein erumpentia, poro apicali vel saepe operculo dehiscentia. Sporophora diversa; alia brevia, simplicia, marginem, loculi vestientia, sporulasque terminales gerentia; alia longioria, interdum septata, sporulas laterales etiam gerentia. Sporulae irregulares uniloculares hyalinæ.

Operculella Padwickii spec. nov.

Pycnidia as in the genus, finally carbonaceous, 270-810μ diameter. Shorter sporophores averaging 83μ in length; longer sporophores bearing spores laterally on minute sterigmata and terminally. Spores hyaline, yellowish-white in mass, $7 \cdot 4\text{-}16 \cdot 6 \times 5 \cdot 5\text{-}11 \cdot 1\mu$.

Habitat.—In dead stems of *Cicer arietinum* L., Karnal, Punjab (December, 1938); Delhi; Gurdaspur, Punjab. Type in Herb. Crypt. Ind. Orient., I. A. R. I., New Delhi.

Latin diagnosis

Pycnidiis ut in genere, postremo carbonaceis, 270-810μ diameter. Sporophoris brevioribus, in medio 83μ longis; sporophoris longioribus sporulas laterales ex sterigmatibus minutis gerentibus. Sporulis hyalinis, in cumulo ochroleucis, $7 \cdot 4\text{-}16 \cdot 6 \times 5 \cdot 5\text{-}11 \cdot 1\mu$.

Hab.—In caulibus emortuis *Ciceri arietini* L., Karnal, Punjab (December, 1938); Delhi; Gurdaspur, Punjab. Typus in Herb. Crypt. Ind. Orient., I. A. R. I., New Delhi.

Summary

A pycnidial fungus which causes foot-rot of gram (*Cicer arietinum* L.) at Karnal (Punjab) and Delhi is described. The fungus belongs to the Sphæropsidaceæ. It produces irregularly shaped, hyaline spores which emerge through a minute apical pore or force open the top of the spherical or discoid pycnidium. The fungus is considered to belong to a new genus for which the name *Operculella* is proposed. The gram foot-rot fungus is named *O. Padwickii*.

Acknowledgements

Grateful acknowledgements are due to Dr G. Watts Padwick, Imperial Mycologist, for the constant interest he took in the diagnosis of this fungus and for going through the manuscript, and to Dr B. B. Mundker for making some useful suggestions.

The author wishes to express his gratitude to Mr E. W. Mason, of the Imperial Mycological Institute, for confirming his opinion with regard to the placing of the species in a new genus and for kindly providing the Latin diagnoses.

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REVIEWS

The principles of fumigation of insect pests in stored produce (H. M. Stationery Office: Pp. 28, 1940; Price 6*d.*)

EVERY year insects damage or destroy millions of pounds worth of stored produce, mainly foodstuffs. The ravages of these destructive pests can be prevented to a great extent simply by keeping the warehouses clean. But if the produce or the warehouse is badly infested, it may become necessary to adopt other methods, such as fumigation, to rid them of infestation. Fumigation is a job which must be carried out by experts. The Department of Scientific and Industrial Research has just issued a pamphlet describing the scientific principles underlying the successful fumigation of insect pests that infest stored produce. This pamphlet is intended to help the expert to apply the results of the most recent findings of science in this important and practical field.

After discussing the varying nature of fumigants and describing suitable apparatus for vapourizing these where necessary, graphs are given to show how stirring the air aids the effective distribution of the fumigant.

Penetration of the gas into the goods depends on how the produce is stacked, while the nature of the building affects the amount of fumigant which will 'cling' or leak away. Suggestions are made for the most effective use of the fumigant, and for ventilation of the building afterwards. Finally the pamphlet deals with the means for observing the effectiveness of the fumigation in killing the insects in all parts of the building.

Insect pests of Burma. By C. C. Ghosh, B.A., F.R.E.S. (Published by Superintendent, Government Printing and Stationery, Burma, 1940: Pp. 216; Price Rs. 7-8)

MR Ghosh deserves congratulations on his book *Insect pests of Burma*, which is a very timely publication, considering that there is at present little available information on the Burman insect pests. In this publication an attempt has been made to acquaint general readers with the elementary facts about insect life and with the common insect pests which have been observed to occur in Burma. Simple methods, wherever possible, have been suggested for action against the pests. Technical descriptions have been reduced to the minimum and the publication appears to be meant primarily for general readers. The book is divided into two parts. Part I deals with general facts about insect life, classification, and the prevention and control of damage by insects, both chemical and biological. Part II deals with the general pests and the pests of the different agricultural crops. In addition, Part II gives useful information on the pests of garden plants, plantation crops, fruit trees and the pests in houses and stores. The get-up of the book is excellent and the illustrations are profuse and very well produced. The book is a valuable addition to the literature on tropical insect pests. (S. C. R.)

PLANT QUARANTINE NOTIFICATIONS

India

Notification No. F. 50-13 (20) 39-A, dated November 20, 1940

In exercise of the powers conferred by sections 4A and 4D of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make, with effect from the 1st February 1941, the following rules for regulating the transport from the Punjab, the North-West Frontier Province and British Baluchistan to any other Province in British India of certain articles which are likely to carry the destructive insect known as San José Scale (*Aspidiotus perniciosus*) and thereby cause infection to crops, namely :—

1. In these rules, ' infected Province ' means the Punjab, the North-West Frontier Province or British Baluchistan.

2. The articles to which these rules apply are :—

(*a*) the following plants, namely, *akik*, alder, almond, apple, apricot, beech, bhang, birch, crab apple, celtis, cherry, chestnut, currant, elm, eucalyptus, grape vine, green-gage, hawthorn, lilac, mountain ash, mulberry, oak, peach, pear, persimmon, poplar, plum, quince, raspberry, rose, strawberry, walnut and willow ;

(*b*) the following plant materials, namely buds, cuttings, scions, grafts, bulbs, leaves, seedlings, tubers and rhizomes, of the plants specified in clause (*a*); and

(*c*) any articles used in packing or wrapping up any of the plants and plant materials mentioned in clauses (*a*) and (*b*).

Note.—These rules do not apply to the fruits of the plants mentioned in clause (*a*).

3. No article to which these rules apply shall be transported from an infected Province to any other Province in British India—

(*a*) by means of letter or sample post or by air,

(*b*) by road except by such routes as may be specified by the Government of the other Province, or

(*c*) by railway or inland steam vessel unless the consignment is accompanied by a certificate in the form set forth in the Schedule annexed to these rules and signed by the authority specified therein.

Schedule

This is to certify that the living plants/plant materials included in the consignment of which particulars are given below were thoroughly examined on .... (*date*) by .... (*name and designation of official*)......................... a duly authorized official of the..................... (*name of Department*).......... and that the consignment including the packing covered by this certificate has been adequately treated and fumigated with hydrocyanic acid gas immediately $\frac{\text{Prior}}{\text{Subsequent}}$ to inspection and made free from living San José Scale.

Date of examination and fumigation ....
Particulars of consignment ....
No. and description of packages ....
Distinguishing marks ....
Description of living plants or plant materials ....
Exported by ....
Name and address of the consignee ....

Signature of certifying authority*- ....

Designation ....

**Note.*—The above certificate should be signed—

(*a*) in the Punjab, by the Entomologist, Punjab Agricultural College, Lyallpur, or such other officer as may be authorized by the Director of Agriculture, Punjab in this behalf,

(*b*) in the North-West Frontier Province, by the Agricultural Officer of that Province, or such other officer as may be authorized by the Provincial Government in this behalf, and

(*c*) in British Baluchistan, by the Agricultural Officer, Baluchistan, or such other officer as may be authorized by the Chief Commissioner in this behalf.

Notification No. F. 50-13 (21) 39-A., dated November 20, 1940

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make, with effect from the 1st February 1941, the following rules for the purpose of regulating the import into British India of certain articles which are likely to carry the destructive insect known as San José Scale (*Aspidiotus perniciosus*) and thereby cause infection to crops, namely :—

1. In these rules, ' infected area ' means the States of Jammu and Kashmir, Chamba, Mandi, Suket, Balsan, Jubbal, Koti, Kumarsain, Madhan, Baghat and Bashahr and the hill tracts of Patiala State comprising the following Parganas, namely :—

Ajmergarh, Baghet, Bagi, Bagri Kalan, Bagri Khurd, Bharoli Kalan, Bharoli Khurd, Chail, Haripur, Jhabrot, Kaimli, Kaljun, Keotan Awal, Keotan Doyam, Khushala, Nali Dharti, Pashgaun and Shatrol.

2. The articles to which these rules apply are :—

(*a*) the following plants, namely *akik*, alder, almond, apple, apricot, beech, bhang, birch, crab-apple, celtis, cherry, chestnut, currant, elm, eucalyptus, grape vine, green-gage, hawthorn, lilac, mountain ash, mulberry, oak, peach, pear, persimmon, poplar, plum, quince, raspberry, rose, strawberry, walnut and willow ;

(*b*) the following plant materials, namely buds, cuttings, scions, grafts, bulbs, leaves, seedlings, tubers, and rhizomes, of the plants specified in clause (*a*) ; and

(*c*) any article used in packing or wrapping up any of the plants and plant materials mentioned in clauses (*a*) and (*b*).

NOTE.—These rules do not apply to the fruits of the plants mentioned in clause (*a*) ;

3. No article to which these rules apply shall be imported from an infected area into British India—

(*a*) by railway or inland steam vessel unless the consignment is accompanied by a certificate in the form set forth in the Schedule annexed to these rules and signed by the authority specified therein, or

(*b*) by land except by the following roads :—

(*i*) Srinagar-Kohala-Murree road ;
(*ii*) Srinagar-Gari Habibullah-Abbottabad-Haripur-Hassanabdal road ;
(*iii*) Srinagar-Jammu-Sialkot road ;
(*iv*) Dalhousie-Pathankot road ;
(*v*) Oot-Kulu road ;
(*vi*) Mandi-Baijnath-Palampur road ;
(*vii*) Bilaspur-Rupar road ;
(*viii*) Fagu-Simla road ;
(*ix*) Theog-Simla road ;
(*x*) Koti-Simla road ;
(*xi*) Kotgarh-Simla road ;
(*xii*) Simla-Kalka-Ambala road.

Schedule

This is to certify that the living plants/plant materials included in the consignment of which particulars are given below were thoroughly examined on ....(*date*) by .... (*name and designation of official*).................... a duly authorized official of the .... (*name of Department*)...........

and that the consignment including the packing covered by this certificate has been adequately treated and fumigated with hydrocyanic acid gas immediately $\frac{\text{Prior}}{\text{Subsequent}}$ to inspection and made free from living San José Scale.

Date of examination and fumigation..
Particulars of consignment ....
Number and description of packages ....
Distinguishing marks ....
Description of living plants or plant materials ....
Exported by ....
Name and address of the consignee ....
Signature of certifying authority* ....

Designation ....

*NOTE.—The above certificate should be signed—

(*a*) in Kashmir, by the Director of Agriculture, Kashmir, or such other officer or officers as may be authorized by the Kashmir Durbar in this behalf.

(*b*) in other States mentioned in rule 1 by such officers as may be authorized by the Durbars concerned.

Notification No. F. 30-7 (34)/37-A., dated December 12, 1940

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

In the First Schedule annexed to the said notification, in columns 2 and 3—

(1) the entry relating to 'Dutch Indies' shall be omitted, and

(2) after the entry relating to 'Mozambique', the following entry shall be inserted, namely :—

Netherlands Indies . . The Department of Economic Affairs

Notification No. F. 193/40 A., dated February 3, 1941

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make the following Order for the purpose of prohibiting, regulating and restricting the import of live insects into British India :—

1. In this Order 'insect' means a living insect, and includes eggs of an insect.

2. No insect shall be imported into British India unless it is accompanied by—

(*a*) a special permit authorizing such importation issued by the Central Government or by an Officer authorized by the Central Government in this behalf ; and

(*b*) a certificate of freedom from disease granted by an Entomologist of the Government of the country of origin.

3. The provisions of paragraph 2 of this Order shall not apply to—

(*a*) bees and silkworms ;

(*b*) parasites and destroyers of injurious insects or other pests intended for the control of such insects or pests, when imported by the authorities of the Institutions named below :—

The Imperial Agricultural Research Institute, New Delhi
The Imperial Veterinary Research Institute, Mukteswar
The Forst Research Institute and College, Dehra Dun
The Public Health Commissioner with the Government of India
The Indian Research Fund Association
The Departments of Agriculture, Madras, Bombay, Bengal, United Provinces, Punjab, Bihar, Central Provinces and Berar, Assam, North-West Frontier Province, Sind, Orissa and Mysore.

United States of America

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

List of United States Department of Agriculture, Bureau of Entomology and Plant Quarantine, Services and Regulatory Announcements

1. *Quarantine and other official announcements* :—Japanese Beetle Quarantine—modifications

2. *Service and Regulatory Announcements*.—January to March 1940

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